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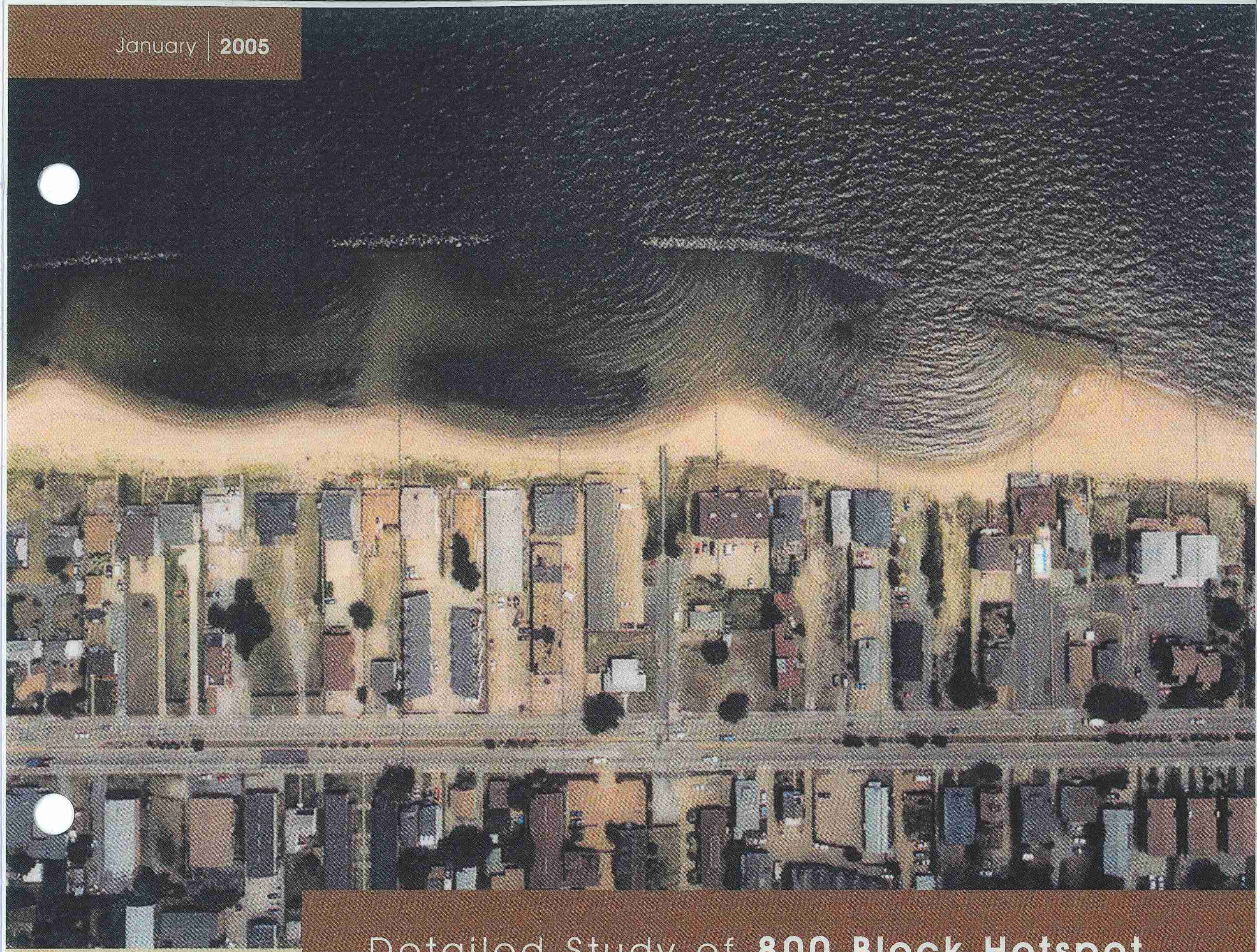

Detailed Study of **800 Block Hotspot**

FINAL REPORT

Moffatt & Nichol

City of Norfolk

EXECUTIVE SUMMARY

The 800 Block area of the City of Norfolk's Ocean View Beach has been a historically eroding hotspot. Dating back to the 1930s, the City has implemented numerous erosion control projects along Ocean View beach to mitigate the shoreline erosion and the development of hotspot areas. Such erosion control projects include beach nourishment and dune restoration, construction of offshore breakwaters, and modification of existing groins and breakwaters. While these efforts have helped to reduce erosion along portions of the shoreline, a severe hotspot between 9th View Street and 7th View Street remains an area of concern.

M&N performed a comprehensive study of historical and present conditions at the 800 Block area to determine the cause of erosion and to develop a recommended alternative for future erosion control. This study involved an intensive review of historical data and engineering activities at the 800 Block area followed by complex numerical modeling of the existing system, all of which aided in the determination of the probable cause of erosion at the study area. The numerical models used in this study include GENESIS (Generalized Model for Simulating Shoreline Change), a one-dimensional (1D) shoreline response model and Delft3D, a three-dimensional (3D) hydrodynamic, sediment transport, and morphological model. The GENESIS model was used to evaluate numerous erosion control alternatives, in which the existing system was modified to mitigate erosional patterns across the study area. Based on the results of the GENESIS model, two alternatives were selected for further modeling in Delft3D. Analytical models were also used to verify the numerical modeling results.

A review of historical data and engineering activities at the 800 Block study area was conducted to develop an initial understanding of historical shoreline change trends across the study area and the impacts which recent engineering activities have had on the study area. The data compiled and analyzed included survey data, shoreline positions, and engineering activities (beach nourishment or construction of erosion control structures). These data sets were used to analyze the shoreline rate of change for successive time periods during which engineering interventions may or may not have influenced the shoreline change. Based on this review of historical data, M&N concluded that the hotspot is located at a unique position along the major bend in the Ocean View shoreline where the site is subject to increased sediment losses due to relative shoreline positions in relation to the predominant wave direction. With the numerous erosion control alternatives that have been implemented, the historical data reveals that longshore sediment transport may have been interrupted on an increasing basis with each structural modification. In particular, the timber groin adjacent to the rock spur was originally too long, blocking significant sediment transport from the east. The addition of the groin spur and breakwater toe extension only increased this blockage of transport.

The scope of the GENESIS modeling task involved evaluating the long-term change in shoreline position based on a long-term period of wave action. To establish the appropriate sediment transport parameters to apply, the model was calibrated for an October 1999 - April 2004 time period using historical shoreline positions and coinciding wave data. Once a calibrated model was developed, the model was run for a number of conditions using the established calibration coefficients. First, the model was used to investigate pre-construction conditions to verify that the model reproduced the erosional hotspot just east of 8th View Street that originally warranted the construction of the groin spur and successive erosion control projects. Next, an existing conditions model was developed and run for a future 13-year time period to determine the impacts with no mitigation of the existing erosion problem. Finally, the calibrated model was used to simulate future long-term shoreline change with numerous erosion control alternative improvements in place. The selected erosion control alternatives were evaluated based on comparisons against the predicted existing shoreline.

Option 1 and Option 4a were selected as the preferred alternatives for further analysis in Delft3D, based on the GENESIS modeling results and comparison of probable costs. Option 1 involves removal of the toe extension on breakwater 7 only. Option 4a involves removal of the toe extension and spur and the addition of a new breakwater offshore. Relative to the predicted future shoreline position under existing conditions, both options are expected to improve the shoreline transition across the entire hotspot extent without worsening conditions updrift or downdrift. The GENESIS model results reveal that Option 4a induces a salient formation behind the new proposed breakwater. With this salient formation, the overall transition of the shoreline appears smoother across the hotspot relative to the resulting shoreline for Option 1.

The Delft3D model was used to assess and compare the relative performance of the preferred alternatives under representative wave/surge conditions. This task involved development of a suite of models and a simulation approach used to examine coastal processes (i.e., hydrodynamics, waves, sediment transport, and morphological changes) under existing, pre-construction (conditions prior to the construction of the spur and toe extension), and future with project conditions for Option 1 and Option 4a. The models were also used to assess and compare the relative performance of these proposed alternatives under wave and hydrodynamic conditions roughly equivalent to a 5-year period.

The Delft3D model results further verify the erosion and accretion patterns that can be expected to occur if Option 4a were implemented. These patterns indicate that while erosion may occur within the embayments between structures, this erosion is less than observed for existing conditions and is more balanced across the entire hotspot with Option 4a implemented. The Delft3D model results for Option 1 indicate more significant accretion behind the existing breakwater 7, which could potentially lead to tombolo formation and further blocking of sediment transport to the west.

Finally, an analytical analysis was performed to further verify the results of the GENESIS and Delft3D models. This analysis involved the estimation of the maximum expected setback between existing and proposed structures by an equilibrium beach planform shape methodology. The results of this analysis further support the numerical modeling results.

Based on the numerical modeling and analytical analysis results, Option 4a is the recommended alternative for erosion control at the 800 Block area. This option involves removal of the toe extension and groin spur and the addition of a new breakwater offshore. The opinion of probable cost for Option 4a is $660,000.

Through this study of the 800 Block area, M&N has gained a full appreciation of the uniqueness of this study area and the special challenges that it has presented others in the past. The historical analyses and numerical modeling results show that the area will always be a hotspot due to the break in the natural shoreline alignment. Therefore, immediate and periodic beach nourishment will always be required here. Based on the numerical and analytical modeling of numerous alternatives, Option 4a will best improve the shoreline transition at this natural hotspot area and balance the sediment transport through this area. If shoreline behavior is still an issue after this project is completed (i.e., if the site wave conditions are different than those used in the study which were transformed from Duck, NC), logical additions to this project would include shortening of the groins and construction of additional breakwaters to the east. However, based on the analysis and modeling to date, these additional measures do not appear cost effective for potential benefits gained.

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I. PROJECT BACKGROUND & SCOPE OF WORK

A. PROJECT BACKGROUND

The 800 Block area of the City of Norfolk's Ocean View Beach has been a historically eroding hotspot (see **Figure I-1**). The area extending from Worth Street to 8th View Street was previously defined as a critical area of concern for erosional damage (Critical Area 1) by Andrews, Miller & Assoc., Inc (AMA) (Jan 1993). In recent years, the City has implemented numerous erosion control projects including beach nourishment and dune restoration, construction of offshore breakwaters, and modification of existing groins and breakwaters to mitigate the erosion problems at this hotspot. While these projects helped to reduce erosion across a portion of the previously defined critical area, the problem has extended eastward and a severe hotspot remains an erosional area of concern between 9th View Street and 7th View Street. This area is the focus of this study.

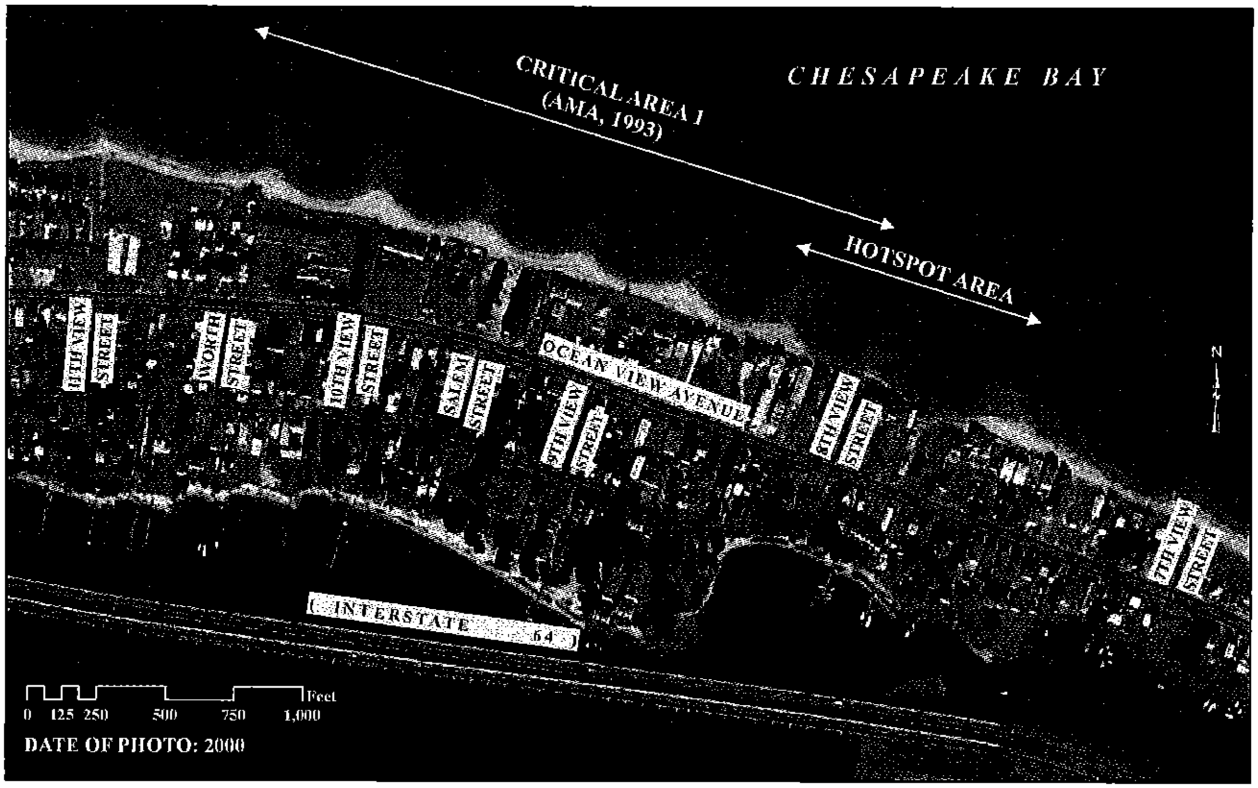
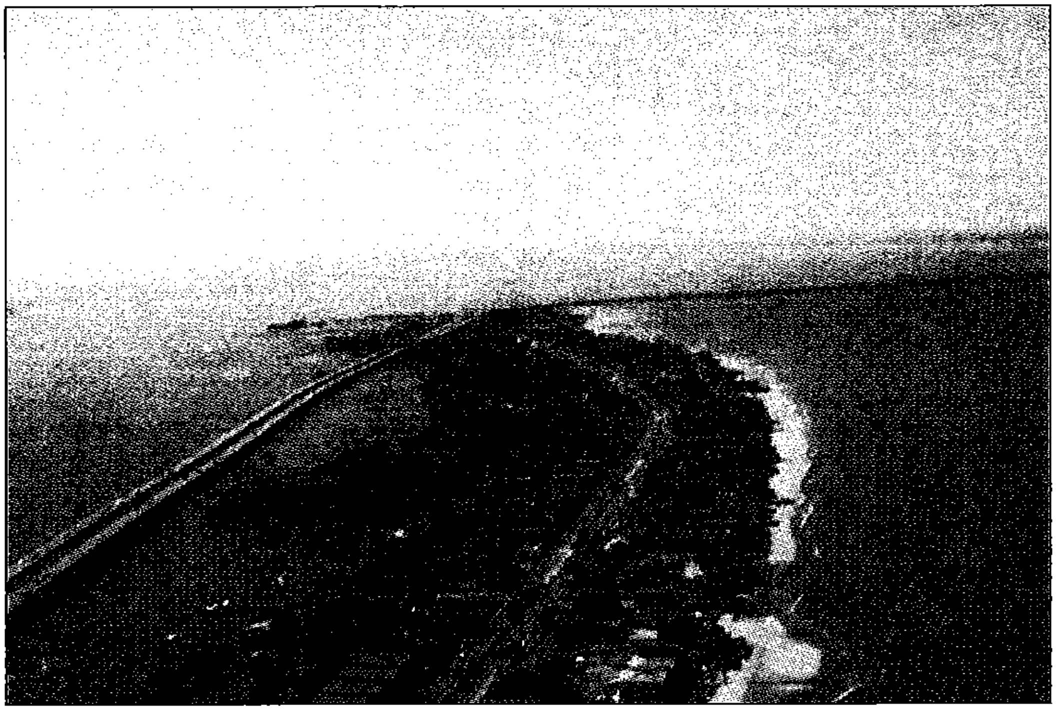


Figure I-1 800 Block Area

The entire Ocean View shoreline is subjected to severe impacts from high tides and wave action during hurricanes and nor'easters. In September 2003, Hurricane Isabel caused extensive damage along the entire City of Norfolk shoreline and surrounding areas. In particular, the 800 Block area suffered loss of the frontal dune system and structural damage to oceanfront homes (see **Figure I-2**).



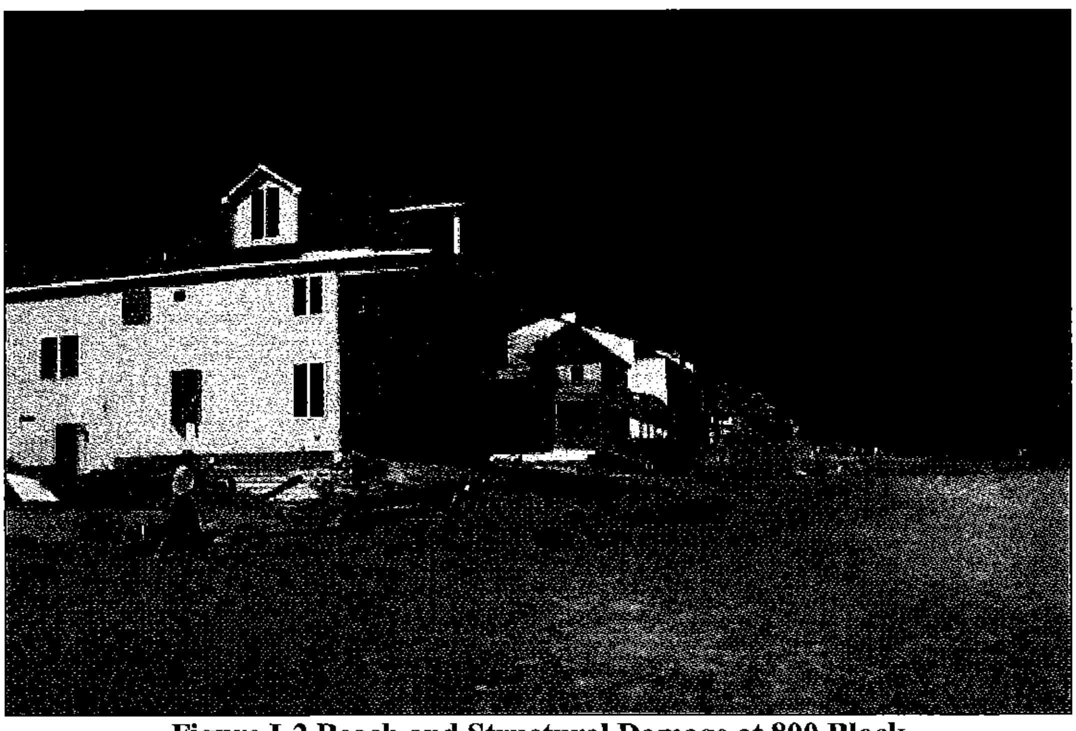


Figure I-2 Beach and Structural Damage at 800 Block

Following Hurricane Isabel, the City performed a post-storm assessment and determined that restoration of the dune field should be undertaken to protect upland property and infrastructure along the shoreline. An emergency truck haul dune restoration project was immediately implemented at three critical areas, which included approximately 36,000 cubic yards (cy) of material for rebuilding dunes in the 800 Block area. This interim project involved construction and vegetation of a dune system with elevation +8 ft NAVD88 from 9th View Street eastward to the rock spur.

Following this emergency truck haul project, M&N was retained to develop final design and plans and specifications for restoration of the shoreline from Willoughby Spit to Central Ocean View. Final bid documents for the project were submitted in June 2004. The source of material for the project was planned as Thimble Shoal Channel. However, permitting issues related to risks to endangered sea turtles from hopper dredging delayed project inception to December 2004. Based on resident concerns over the delay, the City chose to begin a limited interim truck haul project at three sites which includes two sites just east (7th View to 6th View) and west (10th View to 9th View) of the 800 Block area. The truck haul project included a small emergency berm with elevation +8 ft NAVD 88 and total placement of approximately 37,000 cy. This project was completed in Fall 2004.

The original dune and beach restoration project extending from 14th View Street to Warwick Avenue (Willoughby Spit to Central Ocean View) is currently underway using dredged material from Thimble Shoal Channel. Since the dunes in the 800 Block area were restored with the emergency truck haul project immediately following Hurricane Isabel, this project will involve raising the berm to +4 ft NAVD88 and filling to the toe of the breakwaters between 9th View Street and 7th View Street. The total volume of material to be placed in this area is approximately 54,000 cy.

B. SCOPE OF WORK

Along with the continuing efforts to rebuild the beach and reduce erosion at the 800 Block area, the City retained M&N to perform a comprehensive study of the existing system to determine the cause of erosion and to develop a recommended alternative for future erosion control. This study involved an intensive review of historical data and engineering activities at the 800 Block area followed by complex numerical modeling of the existing system, all of which aided in the determination of the probable cause of erosion at the study area. The numerical models used in this study include GENESIS (Generalized Model for Simulating Shoreline Change), a one-dimensional (1D) shoreline response model and Delft3D, a three-dimensional (3D) hydrodynamic, sediment transport, and morphological model. The GENESIS model was used to evaluate numerous erosion control alternatives, in which the existing system was modified to mitigate erosional patterns across the study area. Based on the results of the GENESIS model, two alternatives were selected for further modeling in Delft3D. Finally, the results of the numerical modeling were verified using analytical methods. This report details the following tasks which were involved in completion of this study:

1. Data Collection
2. Review and Analysis of Historical Data
3. Modeling of Shoreline Change with GENESIS
4. Modeling of Coastal Processes with Delft3D
5. Analytical Analysis
6. Study Findings and Recommendations

II. DATA COLLECTION

For the purposes of the historical data analysis, GENESIS modeling, and Delft3D modeling, the following data were required:

- Wave data
- Water level data
- Beach and bathymetric surveys
- Historical shoreline positions
- Sediment data
- Engineering activities log

Much of this data was compiled and collected in previous work completed by M&N for the City of Norfolk including the East Ocean View Beach Nourishment Project design and analysis and the Willoughby Spit to Central Ocean View Dune Restoration project and related work.

The defined coordinate system utilized, where applicable, in this study was State Plane, Virginia South (Zone 4502), NAD 83, with units in feet. The vertical datum used for all elevation data was NAVD88. A mean high water (MHW) elevation of +0.91 ft NAVD88 and mean low water (MLW) elevation of -1.52 ft NAVD88 were assumed for all coastal modeling applications, based on the tidal epoch benchmark (1983-2001 tidal epoch) at the NOAA/National Ocean Service (NOS) Sewells Point gage.

A. WAVE DATA

The wave data used in this study were developed as part of the East Ocean View Beach Nourishment Project design and analysis. A thorough review of nearby and offshore wave data sources was completed to determine the most appropriate data source which would yield a long-term time series of swell and sea waves. Based on a comparative analyses of the available data sources, measured spectral wave data from the USACE Field Research Facility (FRF) in Duck, NC was chosen. The measured spectral wave data was divided into sea and swell components and transformed uniquely to the study area using the MIKE 21 NSW model results, yielding a 13 year time series spanning from 1991 to 2004. For more detail on the wave data development and transformation, please refer to the East Ocean View Beach Nourishment Draft Summary Report (M&N, June 2004).

The wave transformation procedures and the specific wave data used in the GENESIS and Delft3D models will be discussed further in **Section IV** and **Section V** of this report.

B. WATER LEVEL DATA

Water level data were obtained from the NOAA/NOS Sewells Point gage and were used to determine the tidal conditions to apply in the Delft3D model. This methodology will be discussed in more detail in **Section V** of this report.

C. BEACH & BATHYMETRIC SURVEYS

Historical and recent beach and bathymetric surveys collected by the City and Waterway Surveys and Engineering in the 800 Block study area were compiled and are listed in **Table II-1.** This survey data was essential for analyzing the historical erosional patterns and for providing the initial conditions in the GENESIS and Delft3D modeling.

Table II-1 Beach and Bathymetric Survey Data Summary

DATE	SOURCE
Oct 1998	City Surveys
Oct 1999	City Surveys
July 2000	City Surveys
Oct 2000	City Surveys
Oct 2001	City Surveys
July 2002	City Surveys
Oct 2002	City Surveys
Feb-April 2004	Waterway Surveys & Engineering

Digital terrain models (DTM) were built from the survey data sets using the AutoCAD Land Development Desktop (LDD) package. These surfaces were used for extracting shoreline positions, where measured shorelines could not be obtained from aerial photographs. The most recent surface, obtained from the February-April 2004 survey data was the base bathymetry for the Delft3D model runs. The use of these survey data sets and associated DTMs in specific modeling applications will be discussed further in this report.

D. SHORELINE DATA

In addition to the beach and bathymetric survey data, digitized shorelines were obtained for a number of historical and recent dates. A majority of the shoreline data was obtained from a study completed by Dr. David Basco of Beach Consultants, Inc, as part of a comprehensive shoreline analysis for Ocean View Beach (Basco, Jan 2004). Dr. Basco used historical NOAA NOS "T-sheets" (topographic maps) and aerial photographs to delineate shoreline positions dating 1916 to 1999. For the purposes of this study, revisions were made to portions of the Basco data in the 800 Block study area, namely the 1963, 1995, 1999, and 2002 shorelines. Additional historical aerial photos not incorporated in Dr. Basco's study were georectified and shoreline positions were digitized for those dates. **Table II-2** lists the dates and sources for shoreline position data obtained in the 800 Block study area.

Table II-2 Shoreline Data Summary

DATE	SOURCE
1916	NOAA T-Sheet T-3647 (1:20,000)
Sept 1956	Aerial photography
Oct 1959	Aerial photography
1963	NOAA T-Sheet T-11704 (1:20,000)
Feb 1976	Aerial photography
Oct 1995	Aerial photography
March 1999	Aerial photography
Oct 1999	Aerial photography
2000	Aerial photography
June 2002	Aerial photography

In addition to the above shoreline positions delineated from T-sheets and aerial photographs, the MHW contour (+0.91 ft NAVD88) was extracted, where available, from the survey data sets listed in **Table II-1**.

E. SEDIMENT DATA

Sediment data were collected at the 800 Block study area during February to April 2004 in conjunction with the survey data being collected as part of the Willoughby Spit to Central Ocean View Dune Restoration project. This data was reviewed in detail in the Sediment Compatibility Analysis report submitted by M&N to the City in September, 2004 (Moffatt & Nichol, 2004).

In summary, as part of the Willoughby Spit to Central Ocean View project, sediment samples were collected by Waterway Surveys and Engineering along 39 transects, numbered from west to east and spaced at approximately 1000 ft across the Ocean View shoreline. Grab samples were collected at 1) top of dune, 2) toe of dune, 3) mid-beach (halfway between the dune toe and waterline), 4) high water line, 5) elevation -6 feet NAVD88, and 6) elevation -15 feet NAVD88 for each transect.

For this study, samples taken in the 800 Block area were analyzed and a characteristic median grain size (d50) was computed for each sample location. Of the 39 transects sampled, three transects, OV7, OV8, and OV9 were located in the 800 Block study area. The overall effective grain size assumed in this study was an average of the median grains sizes reported for the toe of dune, mid beach, and -6 ft NAVD88 locations on all three transects. The median grain sizes computed for the high water line location were notably high (coarse) and were discarded from the average. **Table II-3** shows the computed median grain sizes at these locations and the resulting computed average of 0.4 mm. This computed median grain size is supported by historical measurements which cite coarse grain sizes ranging from 0.4 to 0.5 mm between Willoughby Spit to Central Ocean View (Waterway Surveys and Engineering, 1984).

Table II-3 Sediment Data Used to Compute Effective Grain Size for Study Area

	MEDIAN GRAIN SIZE (mm)		
STATION	**dune toe**	**mid beach**	**-6 ft NAVD88**
OV 7	0.42	0.53	0.27
OV 8	0.42	0.34	0.21
OV 9	0.47	0.76	0.26
		AVERAGE (mm)	0.4

F. ENGINEERING ACTIVITIES LOG

Information related to engineering projects in the Ocean View area was compiled and was an essential reference for the review of historical data and numerical modeling completed in this study. It is important to consider these activities when examining historical erosional patterns, as shoreline change is significantly impacted by engineering interventions. Furthermore, the project dates and beach nourishment quantities were necessary for calibration of the GENESIS model.

The engineering activities log was compiled from previous work and through discussions and verification with the City. **Table II-4** presents engineering activities including structure construction and beach nourishment projects completed for the entire Ocean View shoreline between 1920 to 2004. Those activities impacting the 800 Block study area are highlighted in the table.

Table II-4 Engineering Activities at Ocean View Beach (1920-2004)

Date	Project Type	Location	Description	Vol (cy)	Extent (ft)
1920-1937	Groin Construction	Willoughby Spit Shoreline	62 groins built by private property owners		
Dec 1926-Jan 1928	Jetty Construction	Little Creek Inlet	East Jetty Construction		
Dec 1926-Nov 1928	Jetty Construction	Little Creek Inlet	West Jetty Construction		
1938	Groin Construction	Between Willoughby Spit and Chesapeake Blvd.	37 timber groins built by City of Norfolk		
1953	Beach Nourishment	18th Bay St to 27th Bay St (East Ocean View)	Beach Nourishment	1,260,000	3,000
1953	Beach Nourishment	27th Bay St to West Jetty (East Ocean View)	Beach Nourishment	500,000	1,800
1960	Beach Nourishment	East End Parking Lot to West Jetty (East Ocean View)	Beach Nourishment	159,000	900
1962	Beach Nourishment	Terminal Groin to 9th View St (Willoughby Spit)	Beach Nourishment	176,000	6,900
1981	Groin reconstruction	Willoughby Spit area	5 timber groins were reconstructed		
1982	Beach Nourishment	East Ocean View	Beach Nourishment	400,000	
1983	Groin Removal	Ocean View Park area	3 groins removed		
1983	Groin Construction	Western end of Willoughby Spit	5 groins built by the City of Norfolk		
Jan-Apr 1984	Beach Nourishment	Terminal Groin to 5th View St (Willoughby Spit)	Beach Nourishment	537,500	11,000
Aug-Nov 1984	Beach Nourishment	21st Bay St to East End Parking Lot (East Ocean View)	Beach Nourishment	400,000	3,000
1985	Beach Nourishment	6th View St to Sarah Constant Shrine Park	Beach Nourishment	50,000	
1987	Beach Nourishment	5th View St to Mason Creek	Beach Nourishment	50,000	2,000
1988	Beach Access Construction	Willoughby and Ocean View	19 pedestrian beach access ways constructed		
Spring 1988	Dune Repair	Willoughby Beach	used 10,000 cy of accretion from terminal groin		
June, 1989	Dune Repair	Willoughby Beach	used 25,000 cy of accretion from terminal groin		
1989	Beach Nourishment	21st Bay St to East End Parking Lot (East Ocean View)	Beach Nourishment	133,000	3,000
1990	Breakwater Construction	Western end of Willoughby Spit-Lea View Ave.	2 near shore breakwaters		
1990	Terminal Groin Reconstruction	Western end of Willoughby Spit-Lea View Ave.	Original wooden groin raised and extended using rock		

Table II-4 Engineering Activities at Ocean View Beach (1920-2004)

Date	Project Type	Location	Description	Vol (cy)	Extent (ft)
1990	Beach Nourishment	Willoughby Spit-Near Terminal Groin	Beach Nourishment	100,000	
1990-1991	Dune Stabilization/repair	Various Locations	dune vegetation planting,sand fence construction, elevated public access way, cross-over structures, and timber roads for vehicles		
1995	Beach Nourishment	Willoughby Spit	Beach Nourishment	240,000	
December, 1995	Beach Nourishment	13th View St to 12 View St (in 4 groin pockets)	Beach Nourishment	4,000	
December, 1995	Beach Nourishment	Critical Area 1: 8th View St to 7th View St	Beach Nourishment	30,000	1,000
March, 1997	Terminal Groin (trunk) Elevated	Willoughby Spit	terminal groin (trunk) elevated +4 ft		
Jan 1997- April 1997	Breakwater Construction	Critical Area 1: Worth St to 8th View	nearshore breakwaters 1-4 constructed		
December 1997 - March 1998	Breakwater Construction	Critical Area 1: Worth St to 8th View	nearshore breakwaters 5-7 constructed		
December, 1998	Beach Nourishment	Critical Area 1: East of 8th View St-near site of future groin spur	Beach Nourishment	500	175
1999	Breakwater Construction	Critical Area 2: Just east of Community Beach	4 nearshore breakwaters constructed		
November-December 1999	Groin Spur Construction	Critical Area 1: Worth St to 8th View	groin spur construction		
December, 1999	Beach Nourishment	Center of COV breakwaters	Beach Nourishment	4,000	
December, 1999	Beach Nourishment	Critical Area 1: East of 8th View St-leeward of newly constructed groin spur	Beach Nourishment	1,000	200
August, 2000	Breakwater Construction	Critical Area 3: 21st Bay to Little Creek Inlet	nearshore breakwaters 2,3,4 constructed		
July, 2001	Beach Nourishment	Critical Area 1: Worth St to 8th View	Beach Nourishment	500	
September, 2001	Beach Nourishment	Critical Area 1: East of 8th View St-between breakwater 7 and groin spur	Beach Nourishment	2,000	300
November, 2001	Breakwater Construction	Critical Area 3: 21st Bay to Little Creek Inlet	nearshore breakwaters 1,5,6,7 constructed		
March - April, 2002	Breakwater Work	Critical Area 1: breakwater 7	work on toe extensions		
May, 2002	Beach Nourishment	Critical Area 1: East of 8th View St-between breakwater 7 and groin spur	Beach Nourishment	3,438	300
June, 2002	Groin Removal	Critical Area 1: Worth St to 8th View	Removal of timber groin channelward of rock spur		
September, 2003	Beach Nourishment	Critical Area 1: West of 8th View St beach access	Beach Nourishment	1,100	350

Table II-4 Engineering Activities at Ocean View Beach (1920-2004)

Date	Project Type	Location	Description	Vol (cy)	Extent (ft)
October, 2003	Beach Nourishment	Critical Area 3: 19th Bay St	Beach Nourishment	6,000	545
October, 2003	Beach Nourishment	Critical Area 3: East of 30th Bay St	Beach Nourishment	1,000	150
December, 2003	Beach Nourishment	Critical Area 3: 17th Bay St to Little Creek Inlet	Beach Nourishment	359,000	5,280
December, 2003	Beach Nourishment	Critical Area 1: 9th View St to 7th View St (+400 ft)	Beach Nourishment	39,800	1,260

III. REVIEW & ANALYSIS OF HISTORICAL DATA

A review of historical data and engineering activities at the 800 Block study area was conducted to develop an initial understanding of historical shoreline change trends across the study area and the impacts which recent engineering activities have had on the study area. The data compiled and analyzed included survey data, shoreline positions, and the engineering activities log (**Table II-4**). These data sets were used to analyze the rate of shoreline change and volume change over successive time periods as presented herein.

A. SHORELINE CHANGE ANALYSIS

Shoreline positions for successive years were plotted on associated aerial photographs to gain an understanding of the relative shoreline erosion and accretion across the study area extent. Shoreline rates of change were computed using a baseline and selected transects (approximately 200 ft spacing along the baseline) from the Basco study (Jan 2004). For each year that a shoreline position was available, the distance from the baseline to the shoreline at each transect was extracted. The shoreline rates of change were then computed for successive years of data by taking the differences in the shoreline position measurements at each transect and dividing by the time, in years, between the two data sets. **Figure III-1** shows the study area extent considered in this historical data review and the transects at which shoreline rates of change were computed. These transects correspond to those used in the Basco study. However, the rates of shoreline change were updated from the Basco study and will be reported for specific time periods herein.

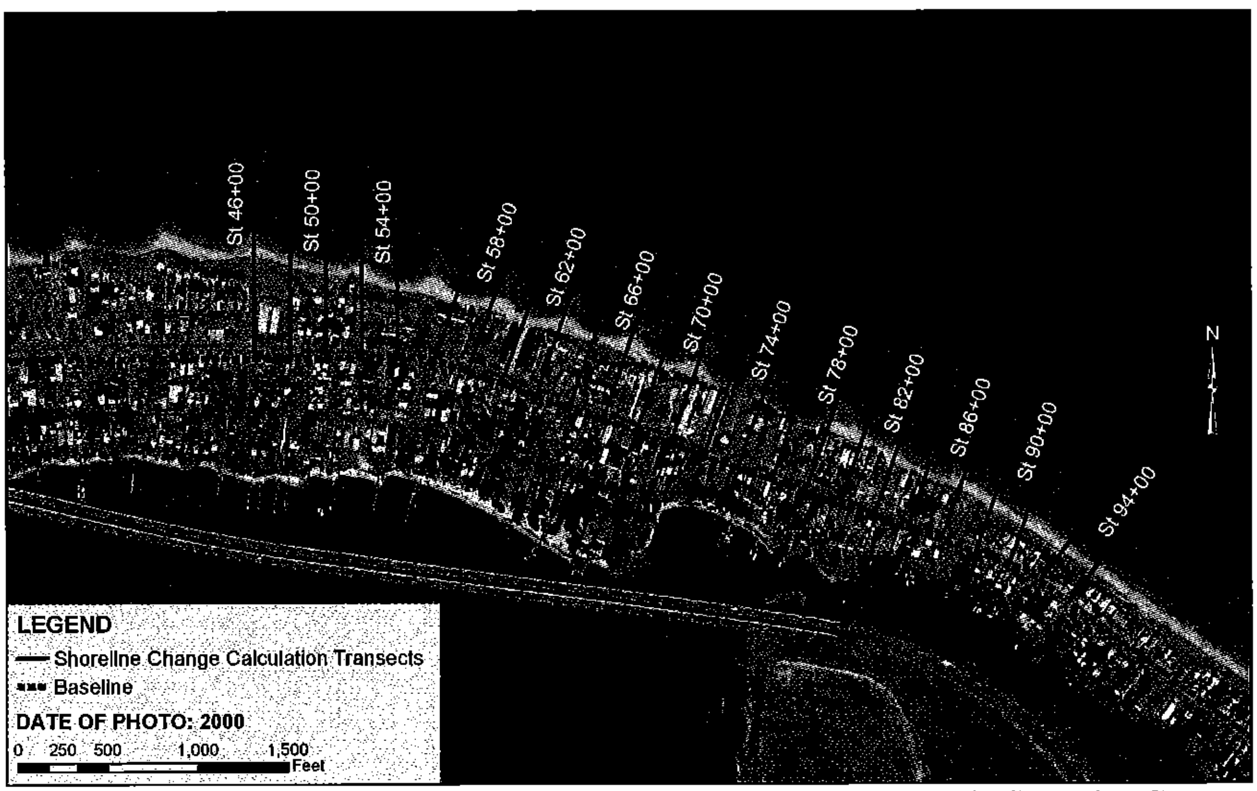


Figure III-1 Extent of Historical Data Analysis and Transects Applied in Shoreline Change Rate Calculations

The following will review the historical shoreline change analysis by presenting for each successive time period, the applicable data sources, relative shoreline positions, coincident engineering activities, and the computed shoreline rates of change across the study area extent. For ease in the presentation of results, all figures referenced in the following discussions are included at the end of this **Section III.A.**

1. 1916 to September 1956

The 1916 (month unknown) shoreline position was obtained from the Basco study in which it was delineated from a NOAA T-sheet. The September 1956 shoreline position was digitized from a historical aerial photo taken of the study area. The engineering projects which were implemented during this time period included:

- 1920 – 1937: construction of 62 groins by private property owners along the Willoughby Spit shoreline
- 1926-1928: construction of the east and west jetties at Little Creek Inlet
- 1938: 37 timber groins built by the City of Norfolk between Willoughby Spit and Chesapeake Boulevard

Figure III-2 presents a comparison of the relative shoreline positions overlain on the aerial photo of September 1956. **Figure III-3** shows the computed shoreline change across the study area transects.

Generally, the shoreline positions indicate shoreline retreat across the study area extent, with the exception of the updrift pockets of the groins present in the 1956 shoreline, which are typically slightly seaward of the 1916 shoreline. These groins were built by the City in 1938, likely for shoreline stabilization following construction of the Little Creek Inlet jetties which reduced sediment transport from the east. There is noticeable shoreline retreat on the west end of the study area where shoreline change rates are on the order of -6 ft/yr. Based on the aerial photography, it appears that this area to the west may have been an erosional hotspot which was later stabilized with numerous beach nourishment projects and by raising the terminal groin at Willoughby Spit.

The average shoreline change rate was computed as -1.11 ft/yr, which indicates minimal overall erosion across the study area. Again, this average rate was further increased by the significant loss shown at the west end of the study area.

2. September 1956 to October 1959

The September 1956 and October 1959 shoreline positions were delineated from aerial photography of the study area. There were no known engineering activities during this time period. **Figure III-4** presents a comparison of the relative shoreline positions overlain on the aerial photo of October 1959. **Figure III-5** shows the computed shoreline change across the study area transects.

The relative shoreline positions for September 1956 and October 1959 indicate more significant shoreline change across the study area than seen for the previous time period. The shoreline change rates vary across the study area, with erosion occurring between stations 56+00 to 60+00 on the west end, and accretion generally occurring across the remainder of the shoreline. Overall trends indicate shoreline accretion, with an average rate of change at +1.94 ft/yr. Based on this analysis, it appears that the timber groins constructed by the City in 1938 were effective at stabilizing a majority of the shoreline from the east up to 9th View Street. However, beginning just west of 9th View Street and moving towards the western end of the study area, the historical data show shoreline retreat. This trend indicates continued loss of sediment from this area around Willoughby Spit.

3. October 1959 to February 1976

The October 1959 and February 1976 shoreline positions were delineated from aerial photography of the study area. In 1962, a beach nourishment project was implemented in which 176,000 cubic yards (cy) of material was placed between the terminal groin at Willoughby Spit and 9th View Street. **Figure III-6** presents a comparison of the relative shoreline positions overlain on the aerial photo of February 1976. **Figure III-7** shows the computed shoreline change across the study area transects.

The relative shoreline positions from October 1959 and February 1976 do not show significant change across the study area extent. With the exception of the area between stations 66+00 and 80+00 (see **Figure III-7**), the shoreline is generally accreting. In the area between stations 66+00 and 80+00, which extend from 9th View Street to just east of 8th View Street, the computed shoreline change rates indicate erosion. However, the rates are not greater than -2 ft/yr. The average shoreline change rate for the study area extent was computed as +0.55 ft/yr. The beach nourishment project which was implemented in 1962 indicates that there were prior erosion problems extending from Willoughby Spit to 9th View Street. With the beach fill placement, the area west of 9th View Street accreted from 1 to 3 ft/yr over the 1959 to 1976 time period.

4. February 1976 to October 1995

The February 1976 and October 1995 shoreline positions were delineated from aerial photography of the study area. During January to April 1984, 537,500 cy of material was placed between the terminal groin at Willoughby Spit and 5th View Street. In addition, the original wooden terminal groin at Willoughby Spit was raised using rock. **Figure III-8** presents a comparison of the relative shoreline positions overlain on the aerial photo of October 1995. **Figure III-9** shows the computed shoreline change across the study area transects.

Despite the large beach fill placement in 1984, the relative shoreline positions from February 1976 and October 1995 show shoreline erosion for a majority of the study area. The shoreline change rates computed over this time period indicate shoreline erosion not exceeding -3 ft/yr between stations 52+00 and 90+00. The westernmost portion of the study area shows accretion ranging from 2-3 ft/yr. However, this accretion is offset by significant losses to the east especially within the area between 7th and 8th View Streets. The overall average shoreline change rate was computed as -0.45 ft/yr across the study area.

The 1993 AMA study was completed in 1993, and defined an erosional area of concern ("Critical Area 1") between Worth Street and 8th View Street. The AMA study concluded that the 1984 beach fill project likely eroded more quickly than expected because the material placed had a high percentage of lightweight shell hash and the placement profile did not extend to the closure depth. In addition, it was suggested that the groin system was filled beyond functional capacity in this beach fill project (Ludwick, 1987). As part of the 1993 study, AMA recommended the construction of seven offshore breakwaters along with beach nourishment to stabilize the critical area at 800 Block.

Based on the historical data and previous studies, it can be concluded that the 800 Block area experienced continued and widened erosion over the 1976 to 1995 time period. It is expected that the original timber groins placed along the study area were further degrading during this time period, thereby increasing the vulnerability of the shoreline to erosion. The underlying aerial photo of October 1995 also shows severe erosion across the study area.

5. October 1995 to March 1999

The October 1995 and March 1999 shoreline positions were delineated from aerial photography of the study area. The engineering projects which were implemented during this time period included:

- 1995: 240,000 cy beach nourishment at Willoughby Spit (exact location unknown)
- Dec 1995: 30,000 cy beach nourishment between 8th View St. and 7th View St.
- Jan-Apr 1997: nearshore breakwaters 1-4 constructed between Worth St. and 9th View St.
- Dec 1997-Mar 1998: nearshore breakwaters 5-7 constructed between 9th View St. and 8th View St.
- Dec 1998: 500 cy beach nourishment east of 8th View St. (near site of future groin spur)

Figure III-10 presents a comparison of the relative shoreline positions overlain on the March 1999 aerial photograph. **Figure III-11** shows the computed shoreline change across the study area transects.

The relative shoreline positions from October 1995 and March 1999 indicate more significant change across the study area extent than seen for the previous time period due to the construction of the offshore breakwater field. With the exception of the area between stations 46+00 and 50+00, stations 76+00 and 80+00 and at station 86+00 (see **Figure III-11**), the shoreline is accreting. In the area between stations 76+00 and 80+00, near the site of the future groin spur, the computed shoreline change rates indicate erosion up to -5 ft/yr. The average shoreline change rate for the study area extent was computed as +8.33 ft/yr.

6. *March 1999 to 2000*

The March 1999 and 2000 shoreline positions were delineated from aerial photography of the study area. The exact month of the 2000 aerial photo is unknown. The engineering projects which were implemented during this time period included:

- Nov-Dec 1999: groin spur construction
- Dec 1999: 1,000 cy beach nourishment east of 8th View St. shoreward of newly constructed groin spur

Figure III-12 presents a comparison of the relative shoreline positions overlain on the 2000 aerial photograph. **Figure III-13** shows the computed shoreline change across the study area transects.

The comparative shoreline positions for March 1999 and 2000 indicate some diminishing of the salient formation behind breakwater 7 (easternmost) and towards the west. The shoreline positions indicate accretion shoreward of and updrift of the newly constructed groin spur. The beach nourishment project implemented in December 1999 may account for some of the accretion observed directly behind the groin spur. However, the overall observed shoreline changes are likely due to increased blocking of sediment transport from the east which was caused by construction of the groin spur. The addition of this structure caused increased sediment buildup on the updrift side of the timber groin, as evidenced by the relative accretion in this area and lessening of sediment transport towards the breakwater field, as evidenced by the decrease in the salient behind breakwater 7. The average shoreline change rate for the study area extent was computed as +2.19 ft/yr. This average accretion is likely due to the overall accretion on the eastern and western ends of the study area, and does not represent the severe erosion (-40 to -50 ft/yr) that occurred between the newly constructed groin spur and breakwater 7.

7. *2000 to June 2002*

The 2000 and June 2002 shoreline positions were delineated from aerial photography of the study area. The engineering projects which were implemented during this time period included:

- July 2001: 500 cy beach nourishment assumed behind groin spur
- Sept 2001: 2,000 cy beach nourishment east of 8th View St. between breakwater 7 and groin spur
- March-Apr 2002: construction of toe extension at breakwater 7
- May 2002: 3,438 cy beach nourishment east of 8th View St. between breakwater 7 and groin spur
- June 2002: removal of timber groin seaward of rock spur between Worth St. and 8th View St.

Figure III-14 presents a comparison of the relative shoreline positions overlain on the June 2002 aerial photography. **Figure III-15** shows the computed shoreline change across the study area transects.

Despite numerous beach nourishment projects which were implemented during the 2000 to June 2002 time period, the relative shoreline positions indicate erosion across all of the study area except near station 74+00 directly behind breakwater 7 (where the majority of the beach fill was placed). In Spring 2002, numerous erosion control projects were implemented including the addition of the toe extension on breakwater 7, the shortening of the timber groin channelward of the rock spur and beach nourishment between breakwater 7 and the groin spur. The most severe erosion, ranging up to -55 ft/yr, occurred directly west of breakwater 7 and behind breakwater 6 where the salient formation was decreased. The previous concentrated hotspot between breakwater 7 and the groin spur remained a narrow beach. However, the erosion rates were reduced to -10 to -15 ft/yr in this area over the 2000 to June 2002 time period compared to the previously observed erosion rates of -20 to -40 ft/yr (1999-2000). However, this reduction in erosion rates is likely influenced by the beach fill placements which occurred during the same time frame. In general, the comparative shoreline positions and corresponding engineering activities indicate that the addition of the toe extension helped to increase the salient formation behind breakwater 7 and reduce erosion at the former hotspot by further shielding this area from wave action. However, this further reduction in sediment transport and the increasing salient behind breakwater 7 increased erosion towards the west of breakwater 7 behind all of the other breakwaters. Overall, the average erosion rate computed for the study area was -16.67 ft/yr for the 2000 to June 2002 time period. Again, it appears from this analysis that the toe extension further blocked littoral transport from the east and this is why increased erosion was experienced.

8. June 2002 to April 2004

The June 2002 shoreline position was delineated from aerial photography of the study area. The April 2004 shoreline position was extracted from a DTM surface built from the beach profile surveys collected by Waterway during February to April 2004. The assumed contour used for representing the shoreline was the MHW elevation of +0.91 ft NAVD88. Just prior to Hurricane Isabel, in September 2003, the City placed 1,000 cy of material west of the 8th View Street beach access. Following the hurricane in December 2003, an emergency truck haul project was implemented in which approximately 36,000 cy of material was placed between 9th View Street and 7th View Street. **Figure III-16** presents a comparison of the relative shoreline positions overlain on the June 2002 aerial photograph. **Figure III-17** shows the computed shoreline change across the study area transects.

This time period begins just following the construction of the toe extension on breakwater 7, removal of the groin seaward of the rock spur, and a small beach nourishment project; all of which occurred during March to June 2002. The final April 2004 survey is representative of the shoreline just four months after the emergency truck haul beach nourishment project in which the dunes along 800 Block were reconstructed and vegetated following Hurricane Isabel. The comparative shoreline positions between June 2002 and April 2004 show relative accretion across the study area extent with substantial accretion between the rock spur and breakwater 5. This accretion is influenced by the beach fill project which was implemented in December, 2003. Therefore, it is difficult to assess the overall effectiveness of the erosion control projects which were implemented in spring 2002 (toe extension, etc.). However, the April 2004 shoreline position shows that the salient formation is more pronounced behind the easternmost breakwaters, where the erosion control structures are locking the beach in place. The average rate of shoreline change computed for the study area for the June 2002 to April 2004 time period is +19.14 ft/yr.

9. Shoreline Change Analysis Summary

In summary, the historical shoreline change analysis confirms that the study area has been an historically eroding hotspot. **Figure III-18** presents the most recent aerial photo of June 2002, with references pertaining to general conclusions to be made from the shoreline change analysis. Despite efforts to improve the shoreline in this area, erosion has persisted. In general, the hotspot area (between Stations 74+00 to 80+00) has been an eroding shoreline over the course of most of the time periods analyzed herein. This excludes some specific locations within the hotspot area (between Stations 74+00 to 80+00), which accreted over certain time periods analyzed due to beach fill placement. Furthermore, it was noted that the hotspot is located along the shoreline bend where there is a natural break in the shoreline position. With this unique location, the position of the shoreline in relation to the predominant wave direction has resulted in increased sediment losses. Finally, the impacts of the added erosion control structures including the spur groin and the toe extension has caused an increasing interruption of longshore sediment transport from the east which has resulted in accelerated erosion at the hotspot.

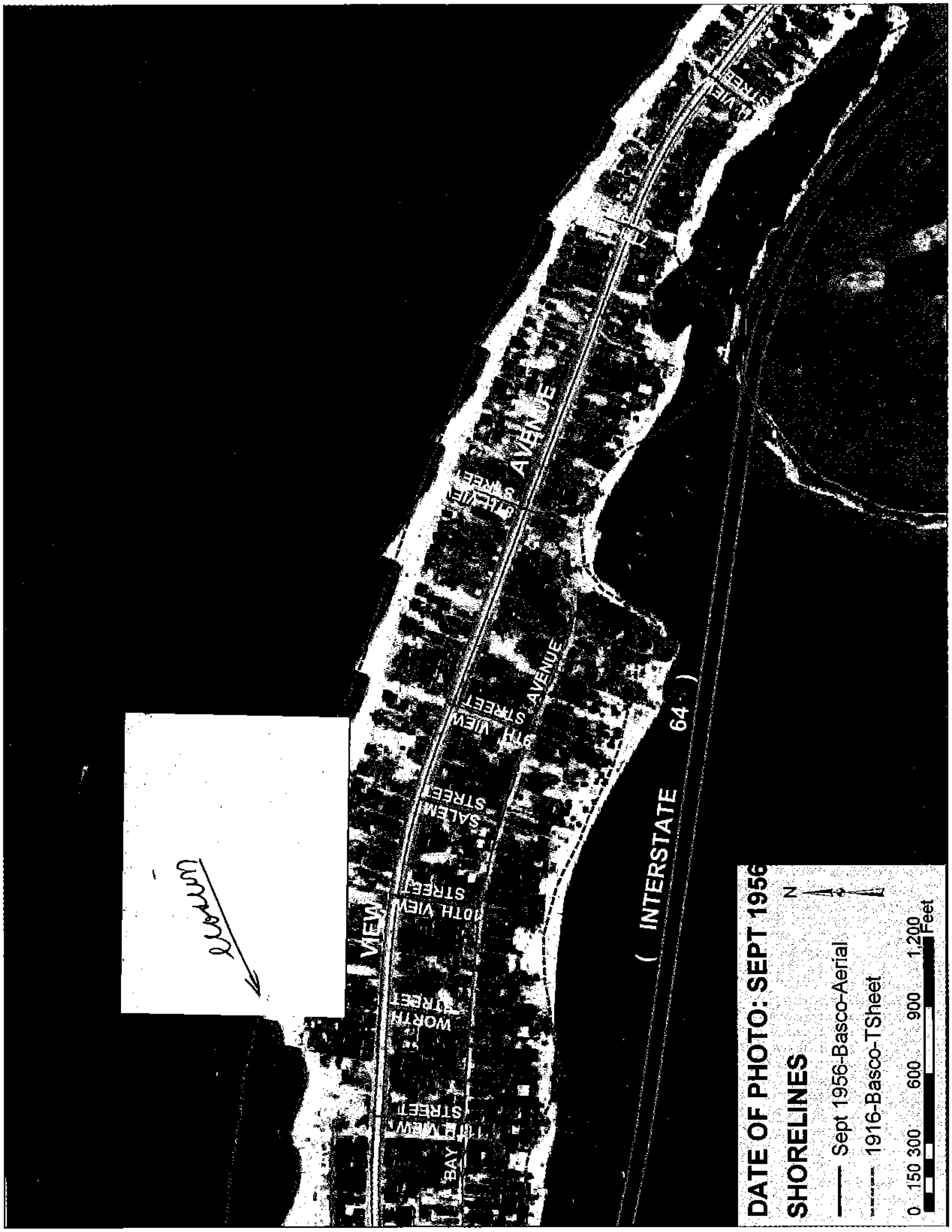


Figure III-2 Comparison of Shorelines - 1916 to Sept 1956

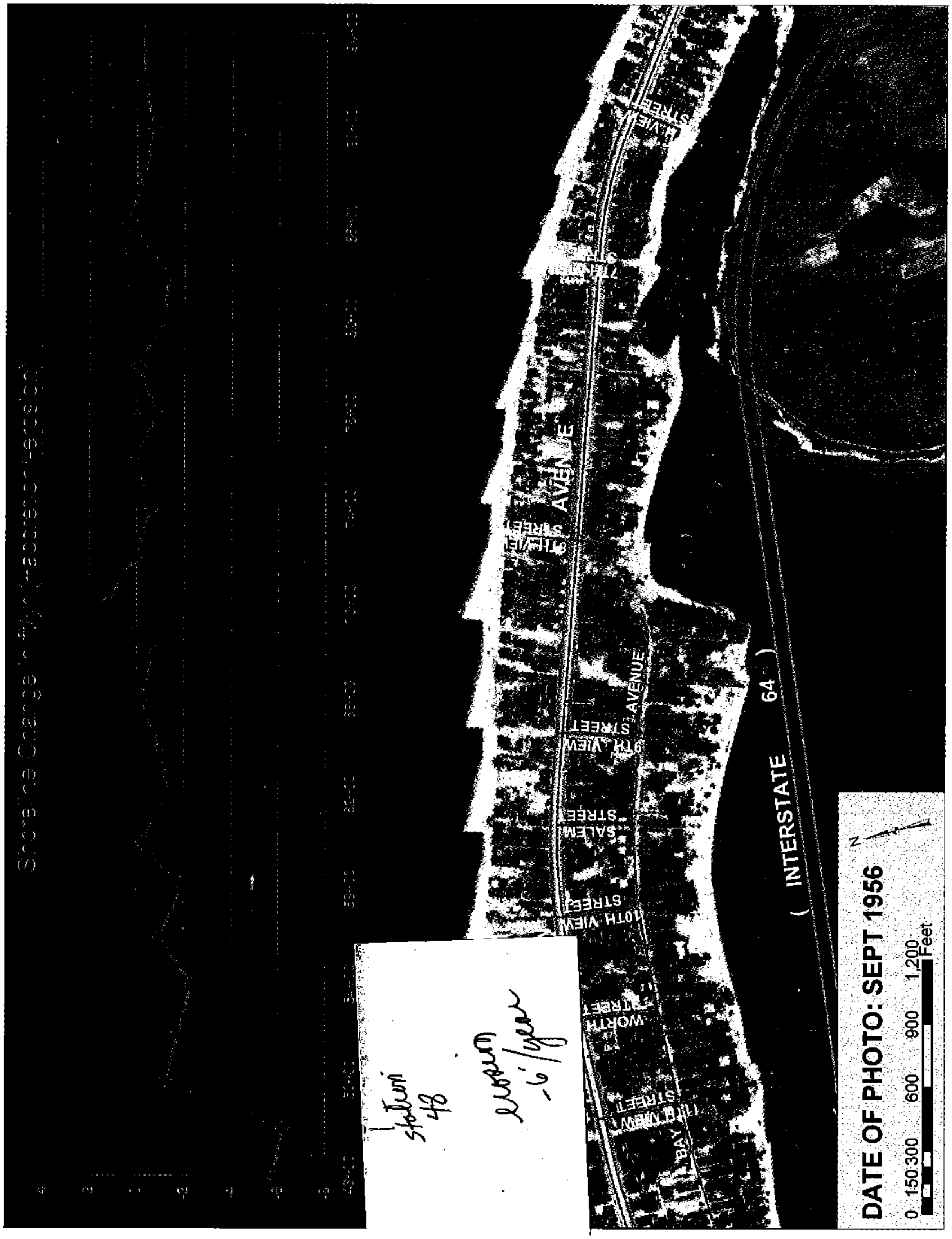


Figure III-3 Shoreline Change (ft/yr) – 1916 to Sept 1956

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Figure III-4 Comparison of Shorelines - Sept 1956 to Oct 1959

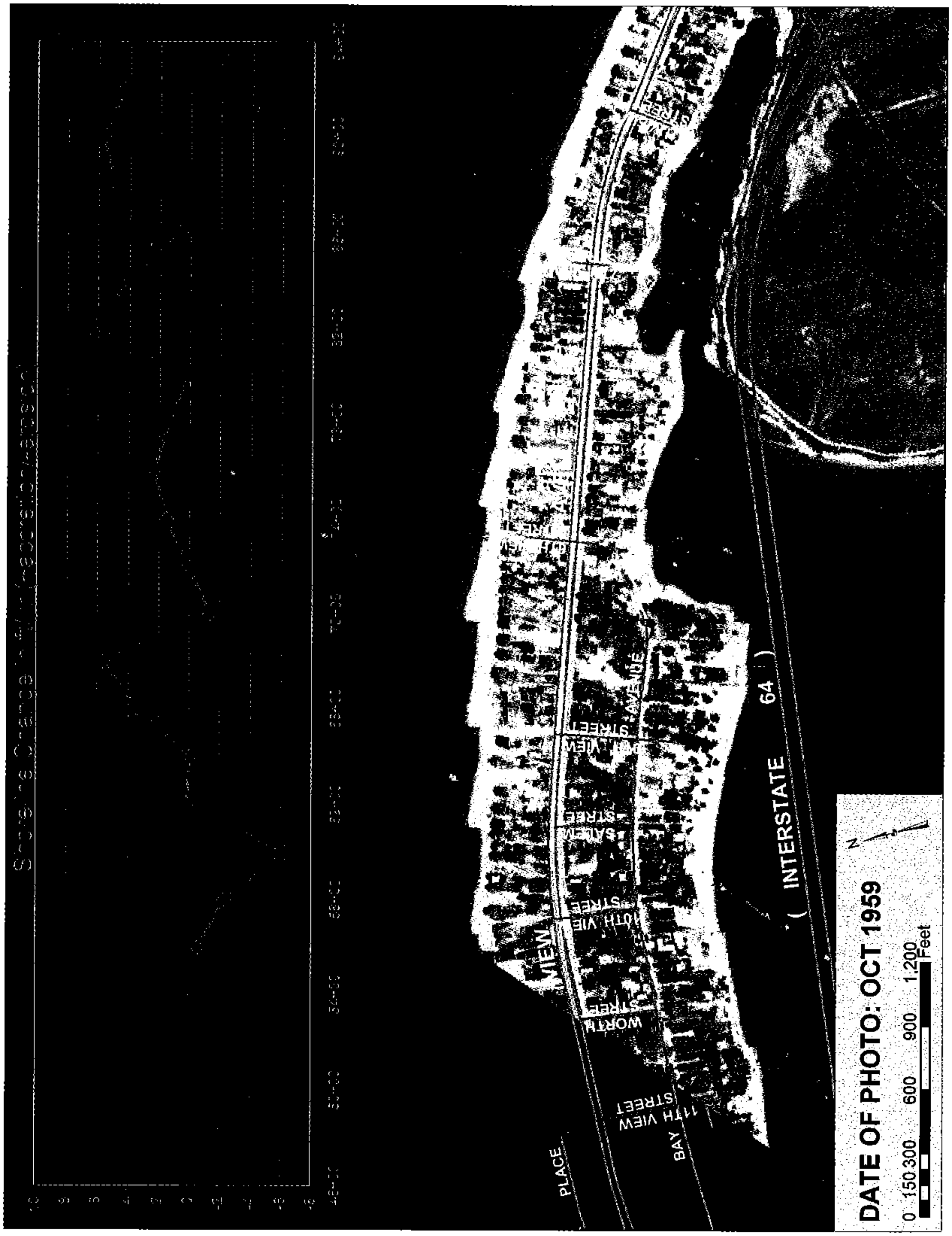


Figure III-5 Shoreline Change (ft/yr) –Sept 1956 to Oct 1959

Figure III-6 Comparison of Shorelines - Oct 1959 to Feb 1976

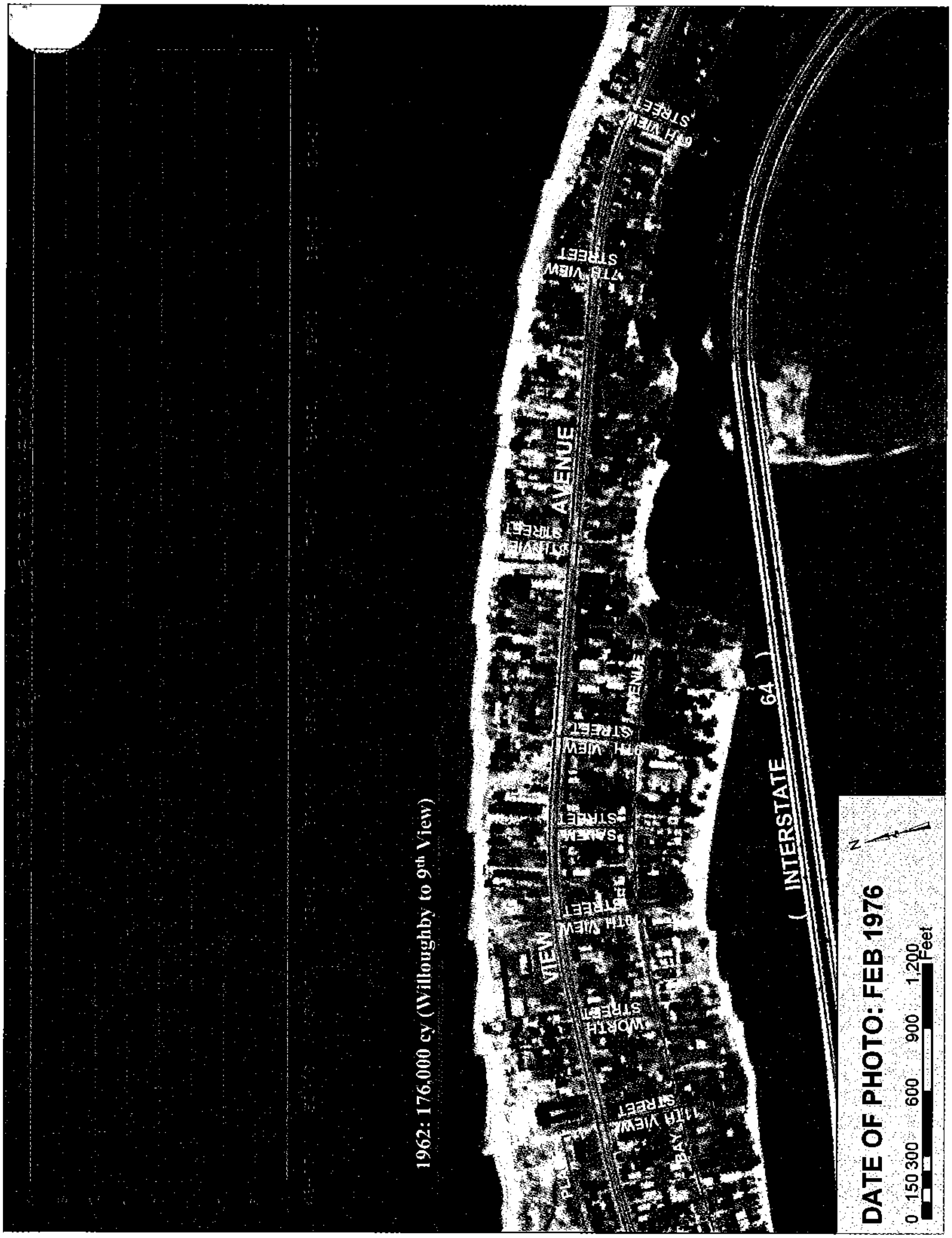


Figure III-7 Shoreline Change (ft/yr) – Oct 1959 to Feb 1976

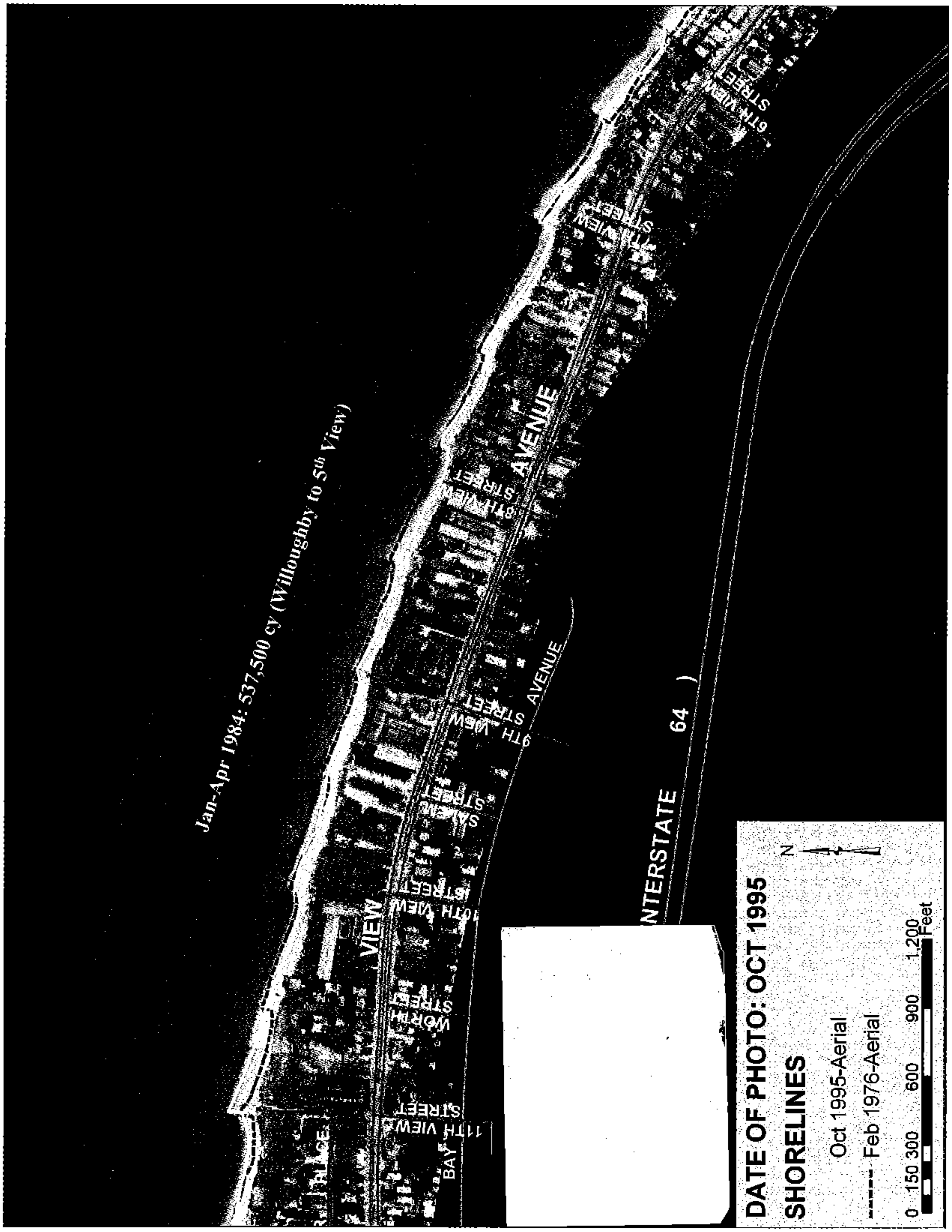


Figure III-8 Comparison of Shorelines - Feb 1976 to Oct 1995

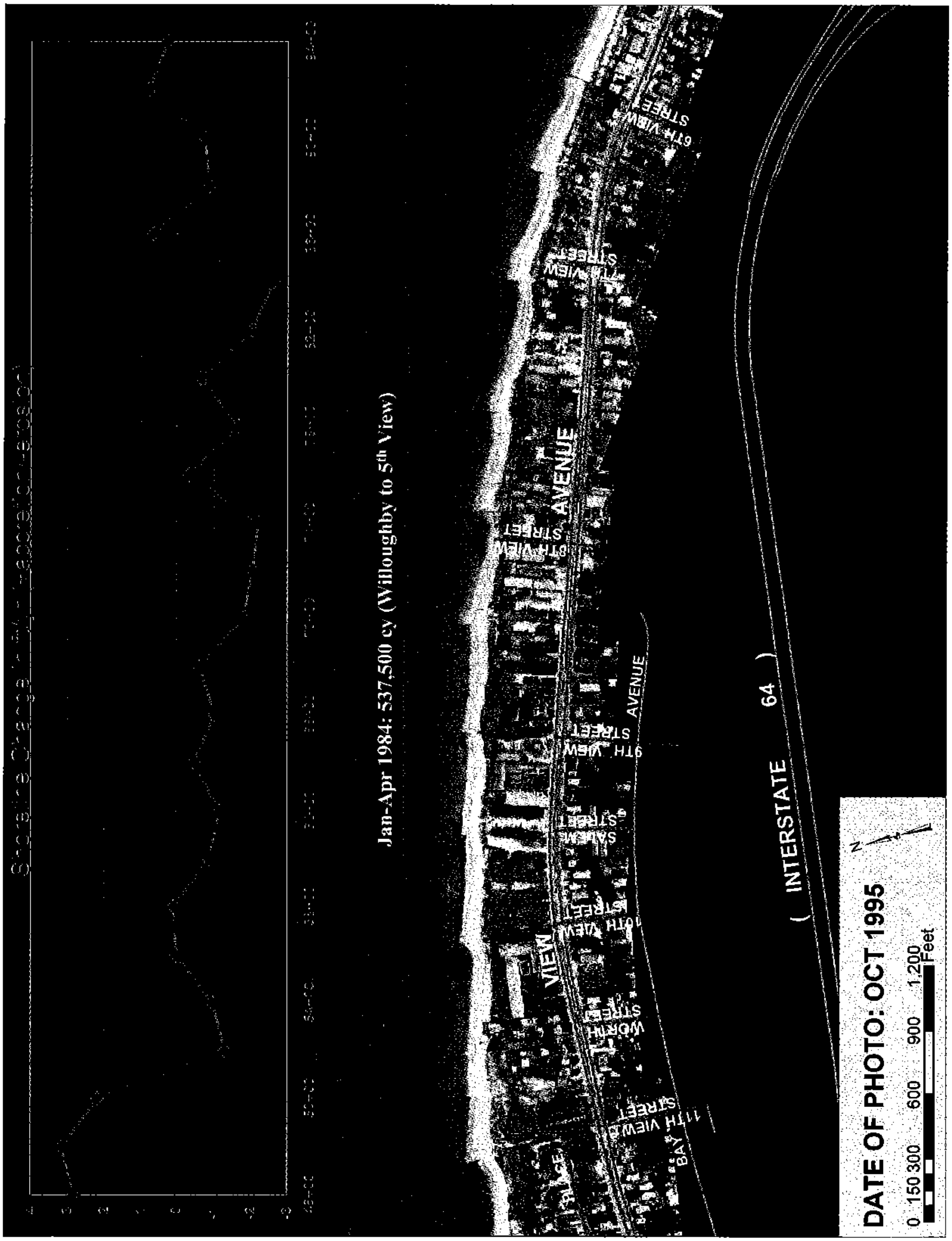


Figure III-9 Shoreline Change (ft/yr) –Feb 1976 to Oct 1995

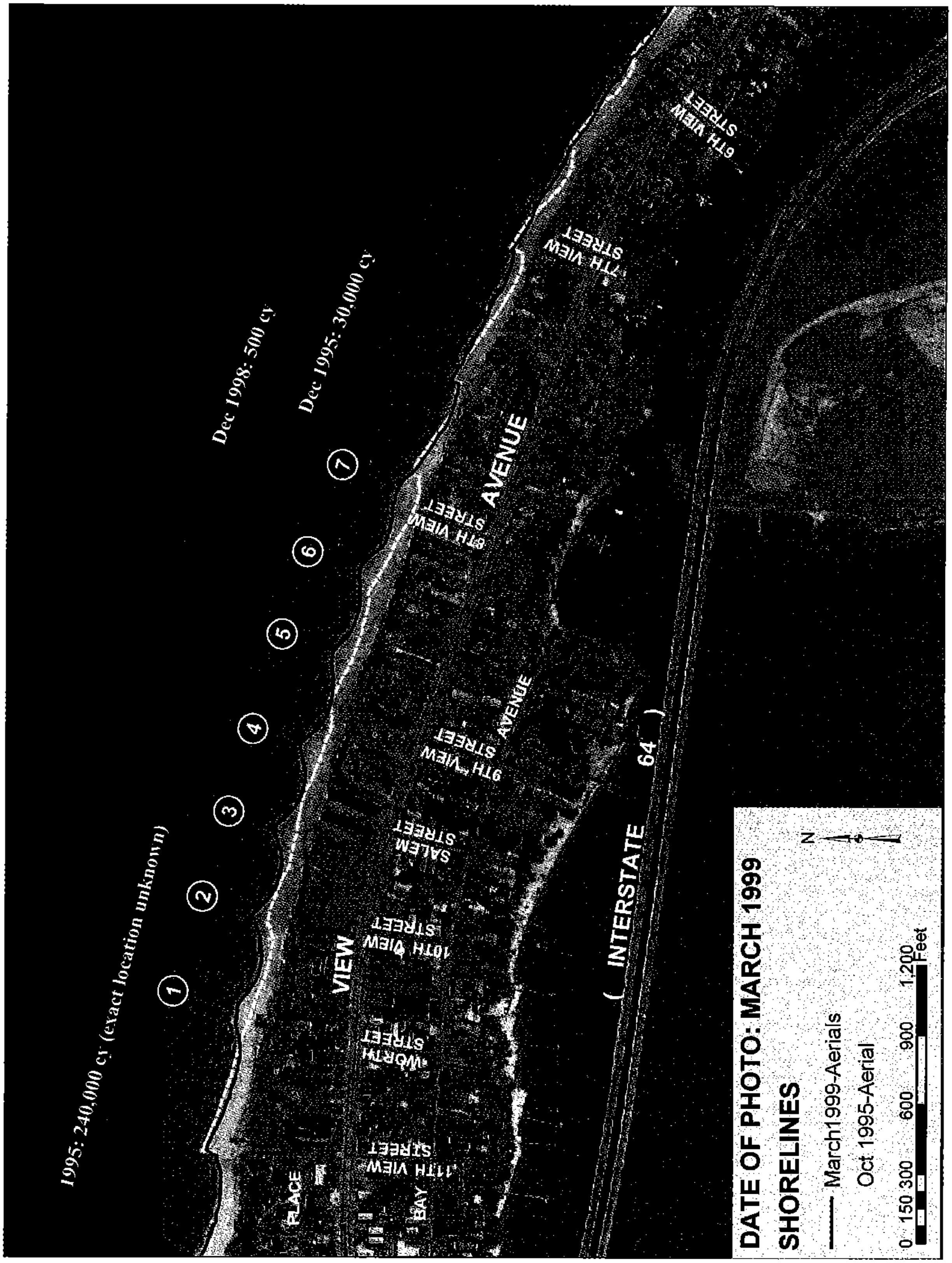


Figure III-10 Comparison of Shorelines - Oct 1995 to Mar 1999

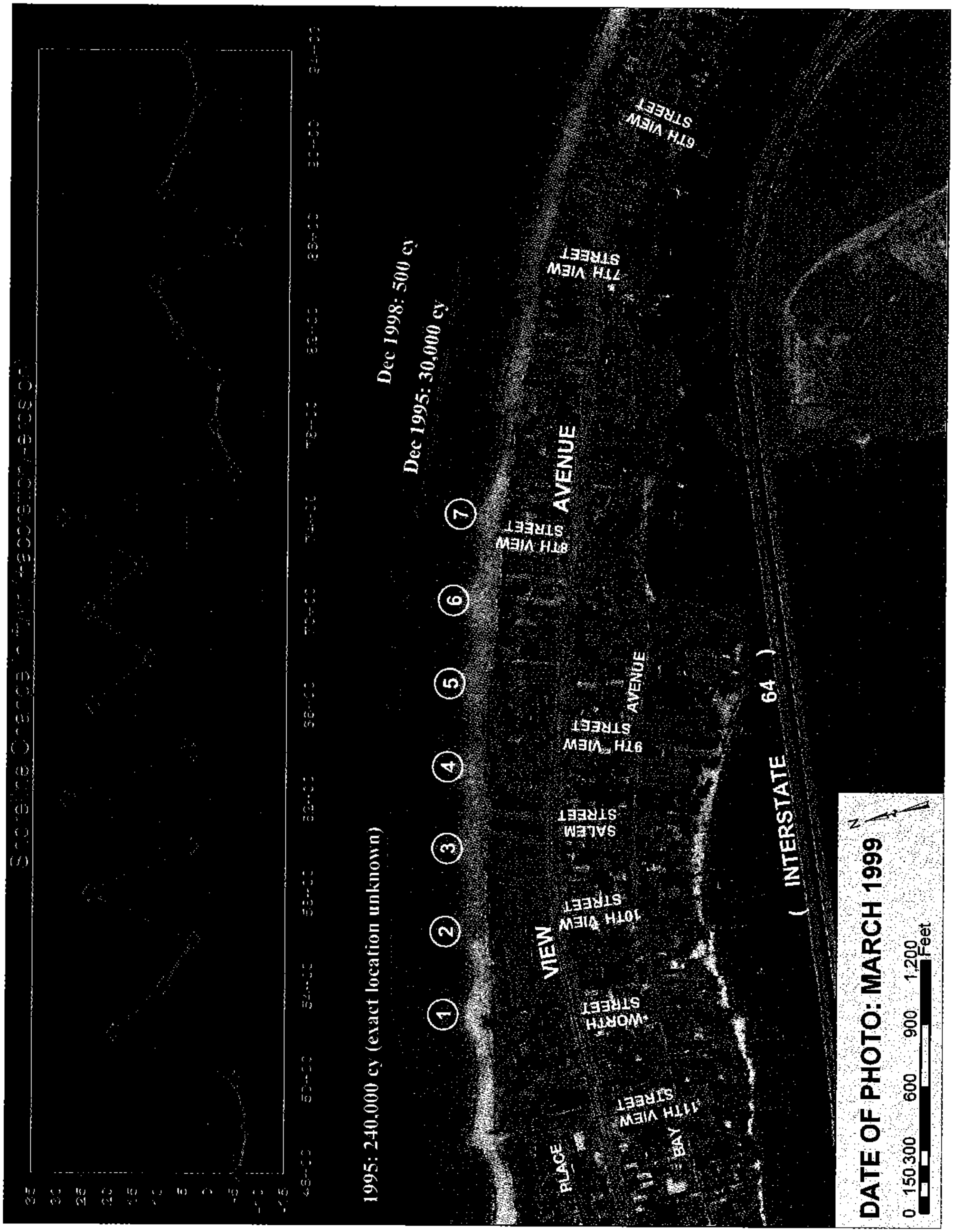


Figure III-11 Shoreline Change (ft/yr) – Oct 1995 to Mar 1999

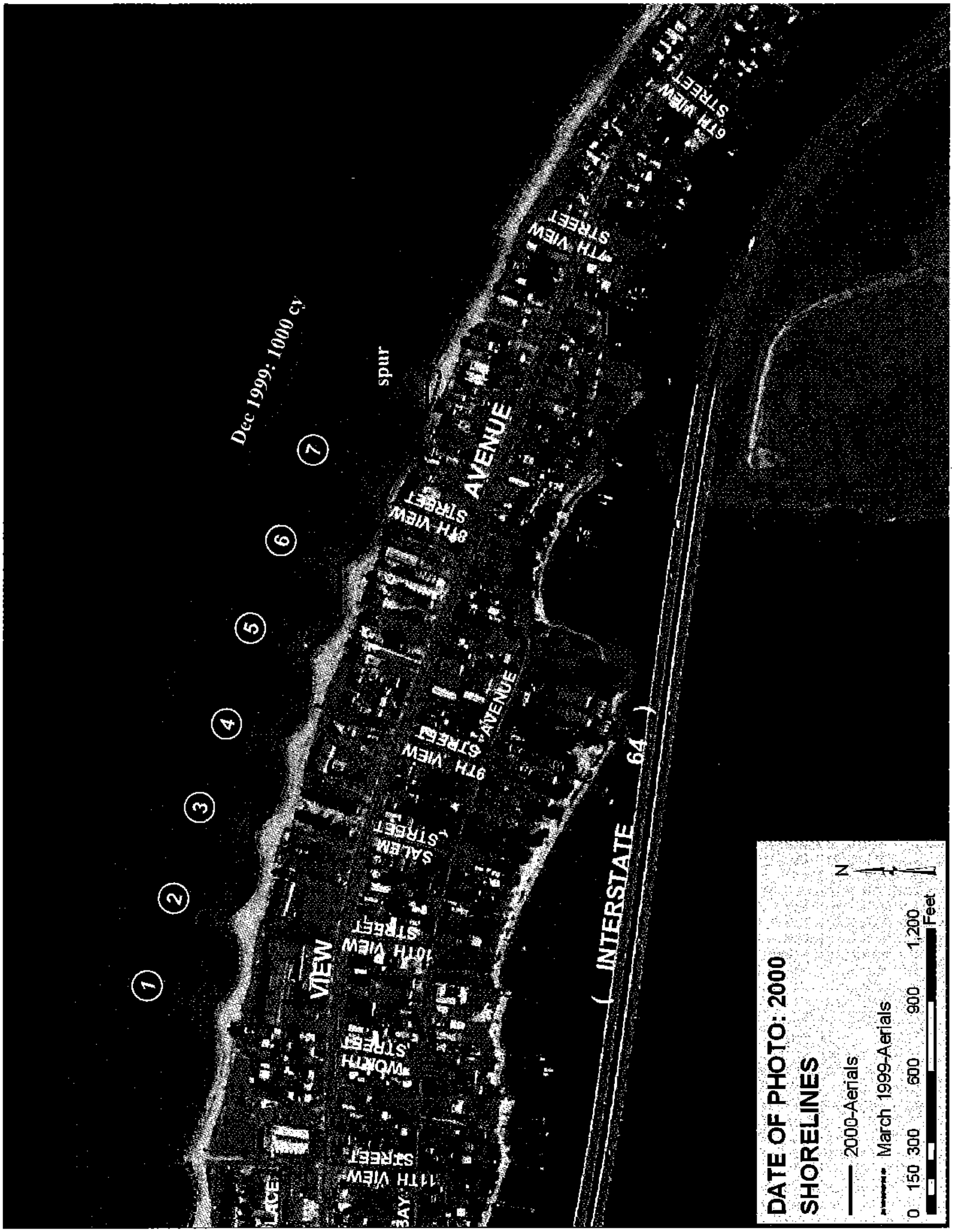


Figure III-12 Comparison of Shorelines - Mar 1999 to 2000

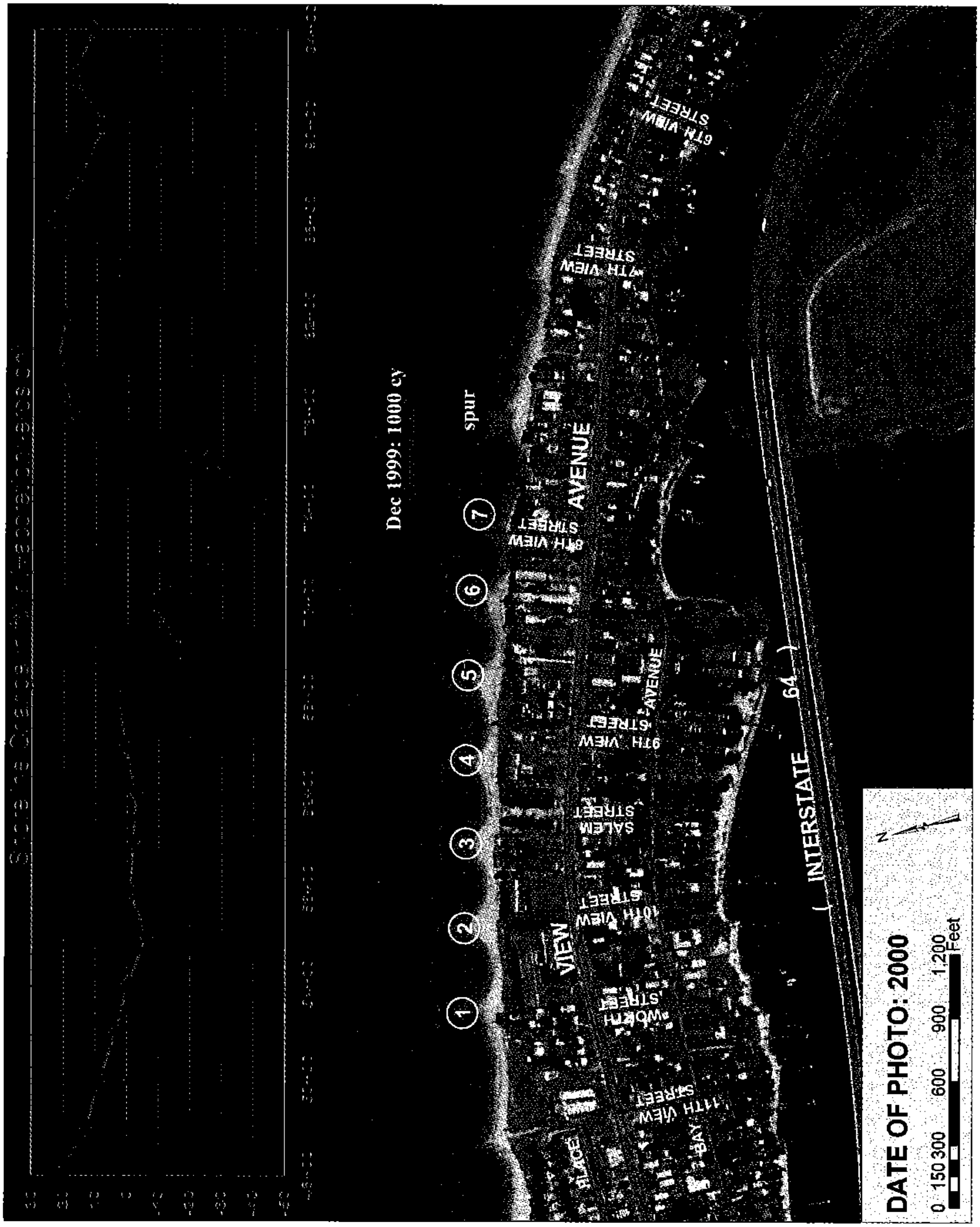


Figure III-13 Shoreline Change (ft/yr) – Mar 1999 to 2000

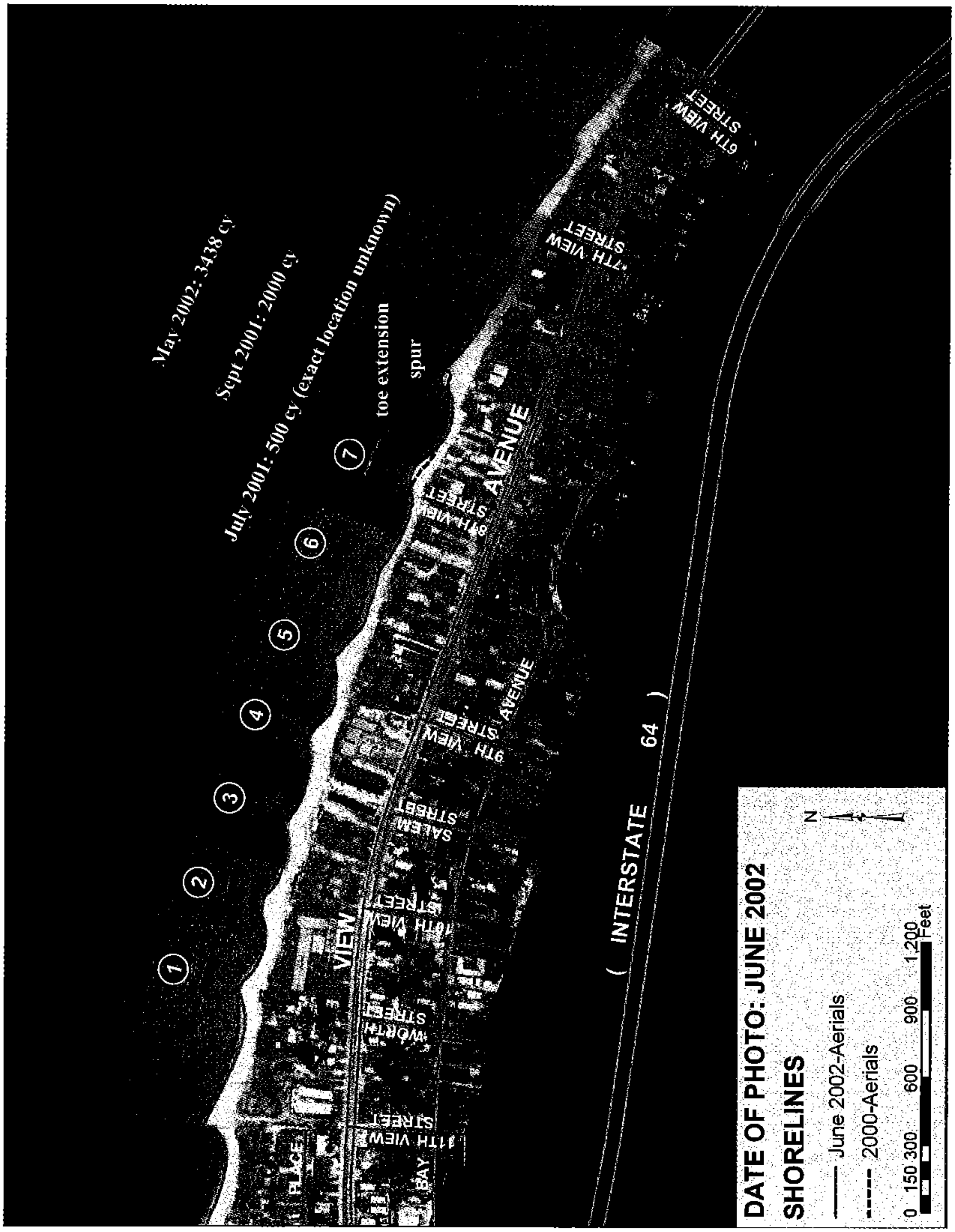


Figure III-14 Comparison of Shorelines - 2000 to June 2002

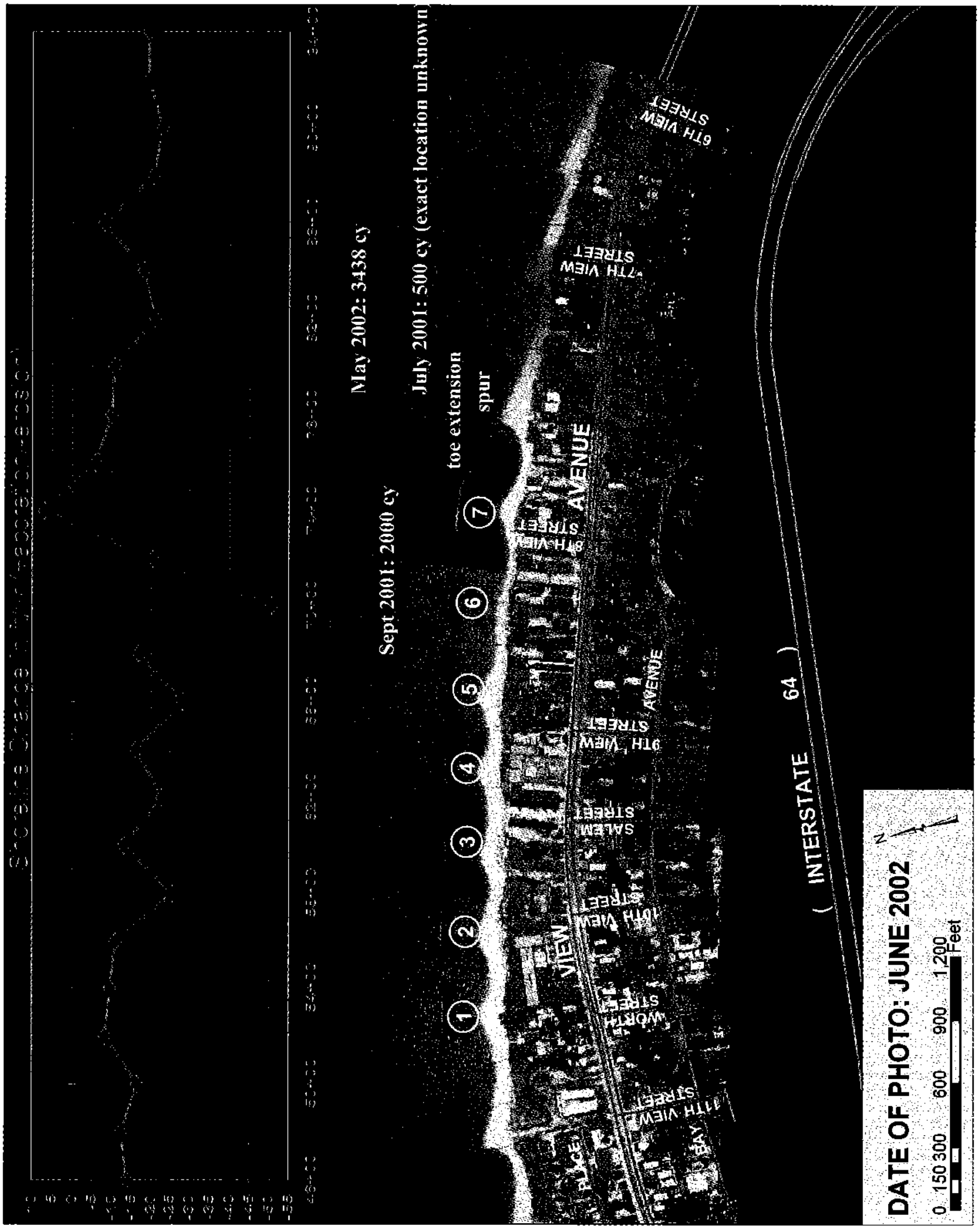


Figure III-15 Shoreline Change (ft/yr) –2000 to June 2002

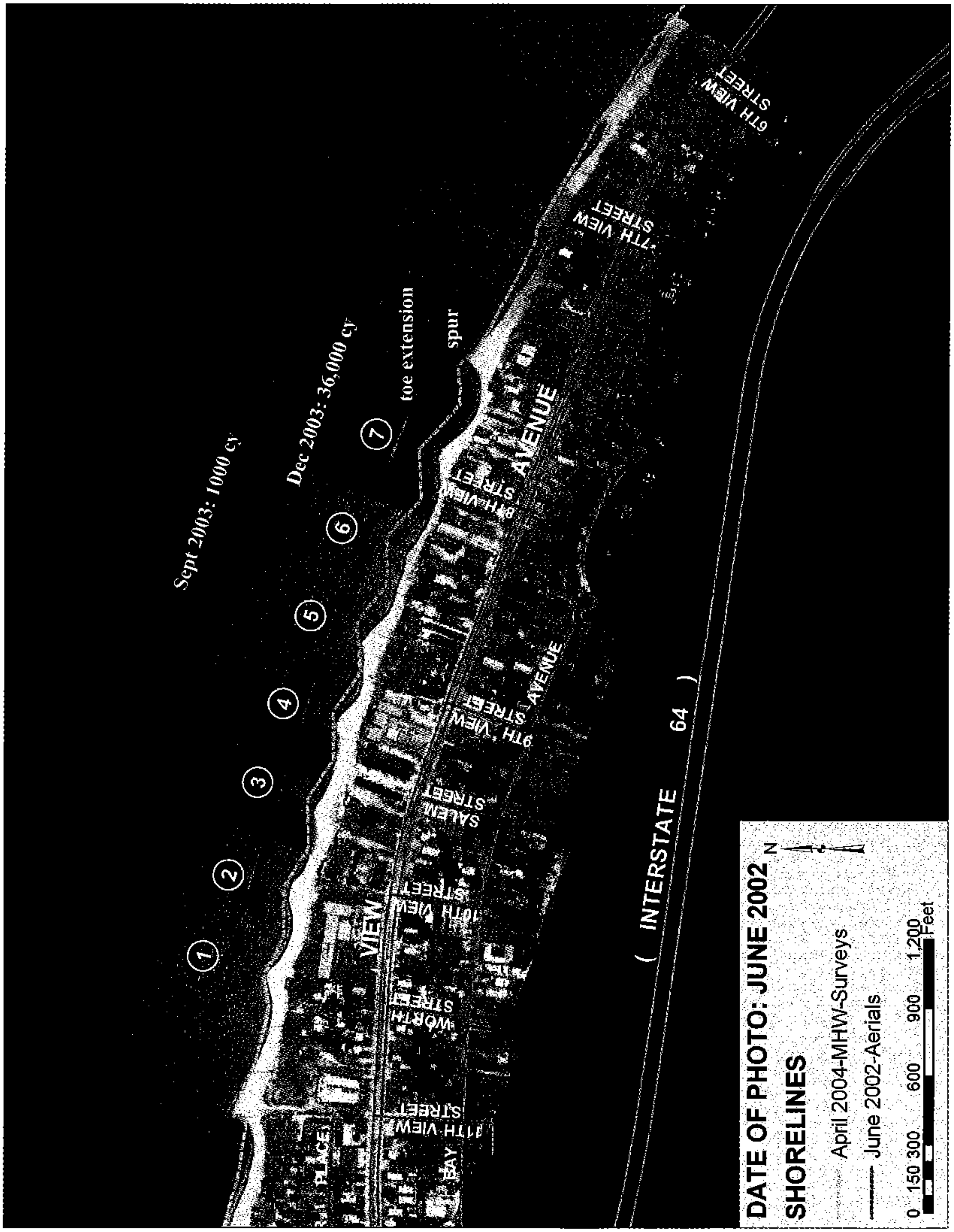


Figure III-16 Comparison of Shorelines - June 2002 to April 2004

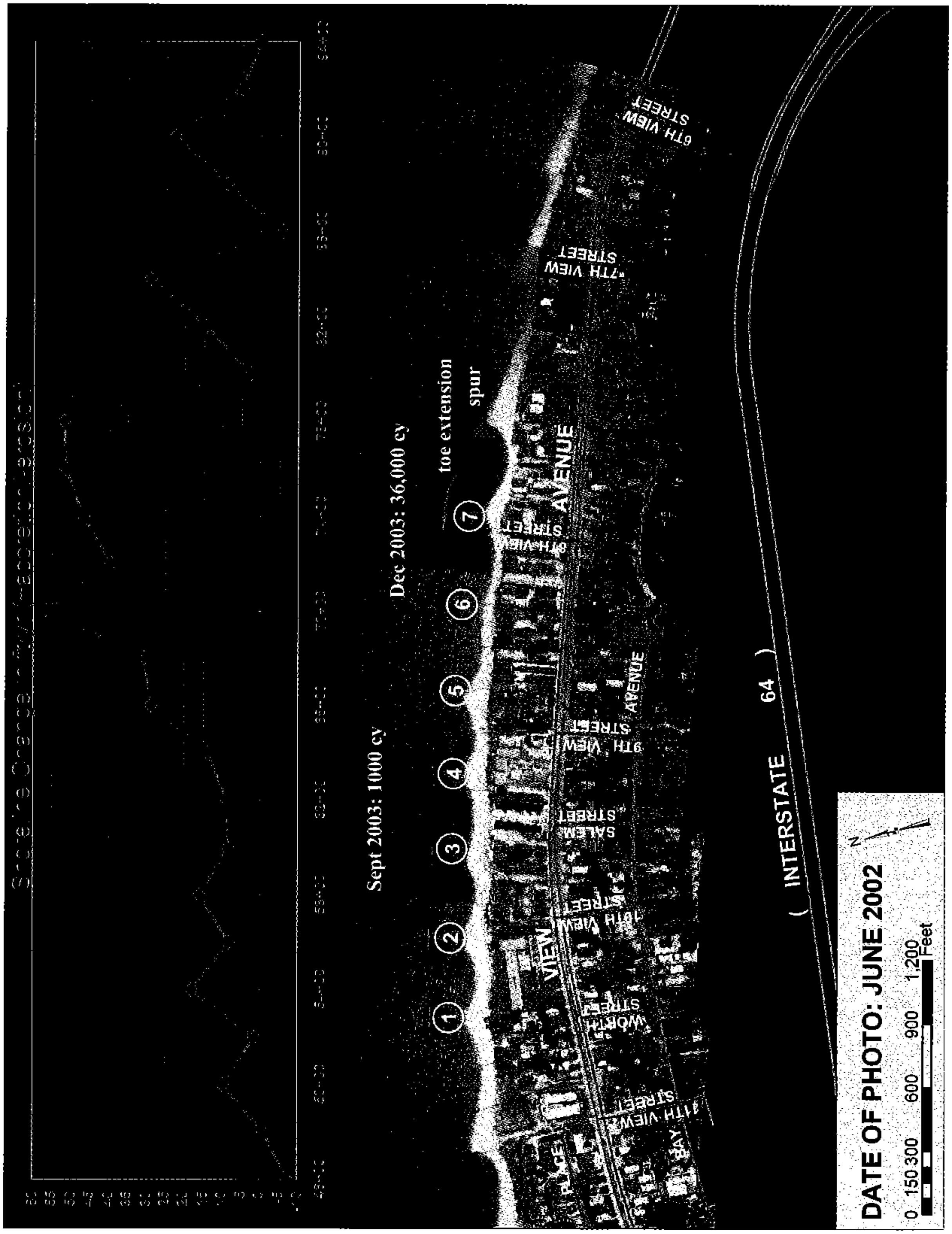


Figure III-17 Shoreline Change (ft/yr) – June 2002 to April 2004

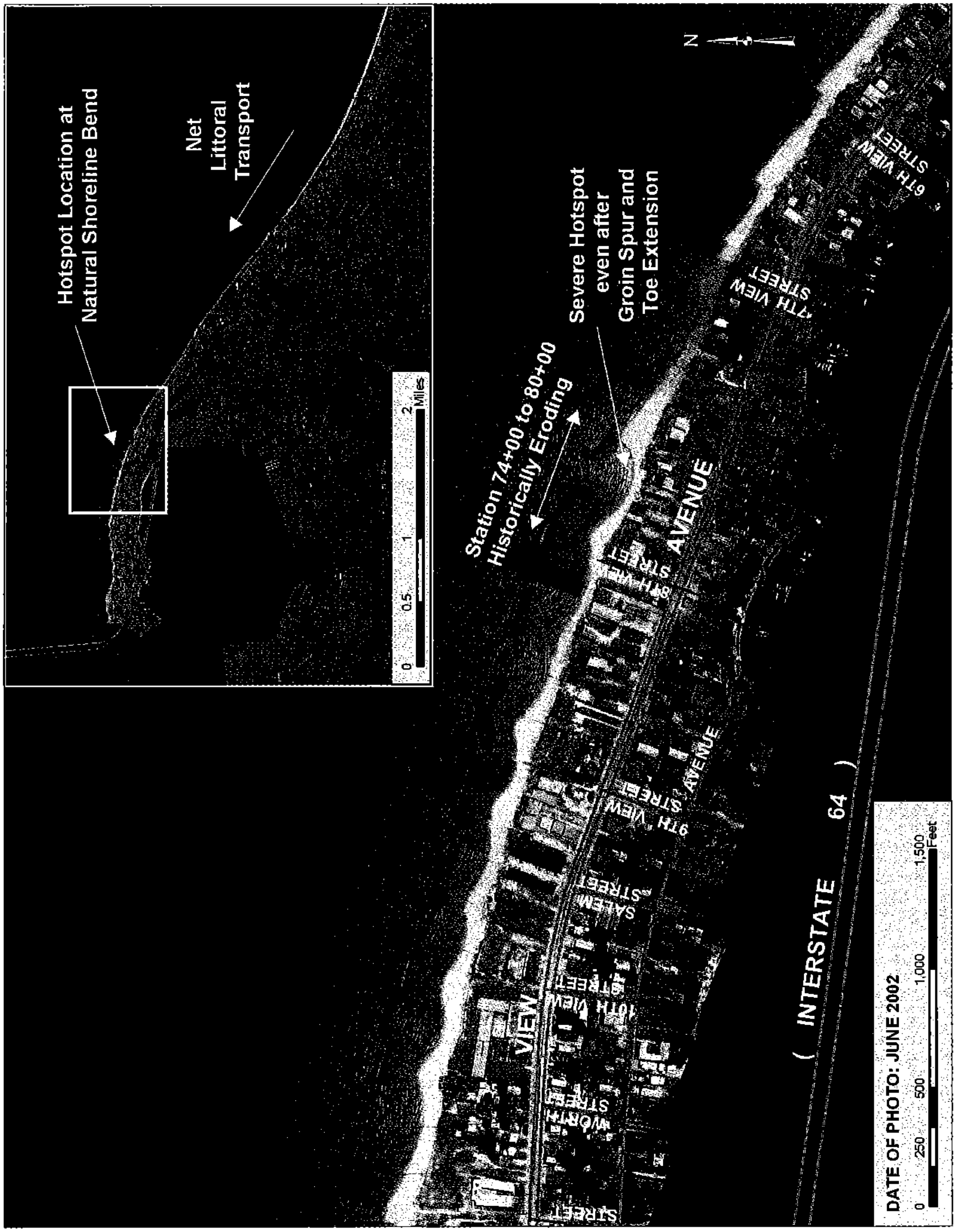


Figure III-18 Summary of Shoreline Change Analysis Findings

B. VOLUME CHANGE ANALYSIS

In addition to the direct shoreline change computations, a volume change analysis was performed to provide an indication of the shoreline response to beach fill placement. This analysis used several dates of surveyed beach profiles (see **Table II-1**) to compute the volumetric change accounting for the relative erosion/accretion and the volume added from beach nourishment activities. The results of this analysis provide an indication of the relative accretion caused by fill projects, when the actual underlying shoreline response may be erosion.

The surveyed beach profiles which were used in the volume change analysis were from October 1999, July 2002, and April 2004. The survey dates allowed for comparison of two successive time periods: 1) October 1999 to July 2002 and 2) July 2002 to April 2004. For each set of successive dates, overlapping profiles were compared to compute a two-dimensional (2D) profile change. This 2D change was then applied along the shoreline using the average-end-area method, yielding the total volume change over the given time period. The volume change per year was then computed using the time in decimal years between the two surveys in question. Finally, the volume change per year due to beach nourishment projects was computed by prorating the volume of fill across the placement extent during the time period and dividing this volume by the time in decimal years.

The results of this analysis are presented for the two time periods analyzed.

1. October 1999 to July 2002

The profile comparisons were made using the City survey data obtained in October 1999 and July 2002 at six locations across the study area extent at which overlapping profiles were available. The profile comparisons were made across the dune and beach face to offshore depths ranging from -5 ft NAVD88 to -15 ft NAVD88. The limit of profile data at a given location defined the offshore depth to which the profile comparison was made. The 2D profile change was applied across a representative alongshore extent, based on the locations of available profiles. **Figure III-19** shows the resulting volume change rates and volume fill rates across the study area for the October 1999 to July 2002 time period. The extents to be discussed are labeled in the figure as a reference.

The resulting volume change rates indicate that despite beach fill placement near breakwaters 6 and 7, the net result along the shoreline (Area D) was erosion based on the profile comparison in this area. The volume fill rate computed for this area was 963 cy/yr. However, the volume change rate over the time period was -1492 cy/yr, yielding a net loss of approximately 2500 cy/yr and indicating that the material placed was removed from the system. At the site of the groin spur (Area E), which was constructed in December 1999, the profile analysis indicates that nearly 90% of the material which was placed near the groin spur remained in place. There was no beach fill placed updrift of the groin spur (Area F) during the time period in question. However, the volume change rates indicate accretion in this area. This accretion may be due to construction of the groin spur which further blocked sediment transport from the east. At Areas A, B, and C, on the western end of the study area, the profile analysis indicates net erosion with no material placed in this area.

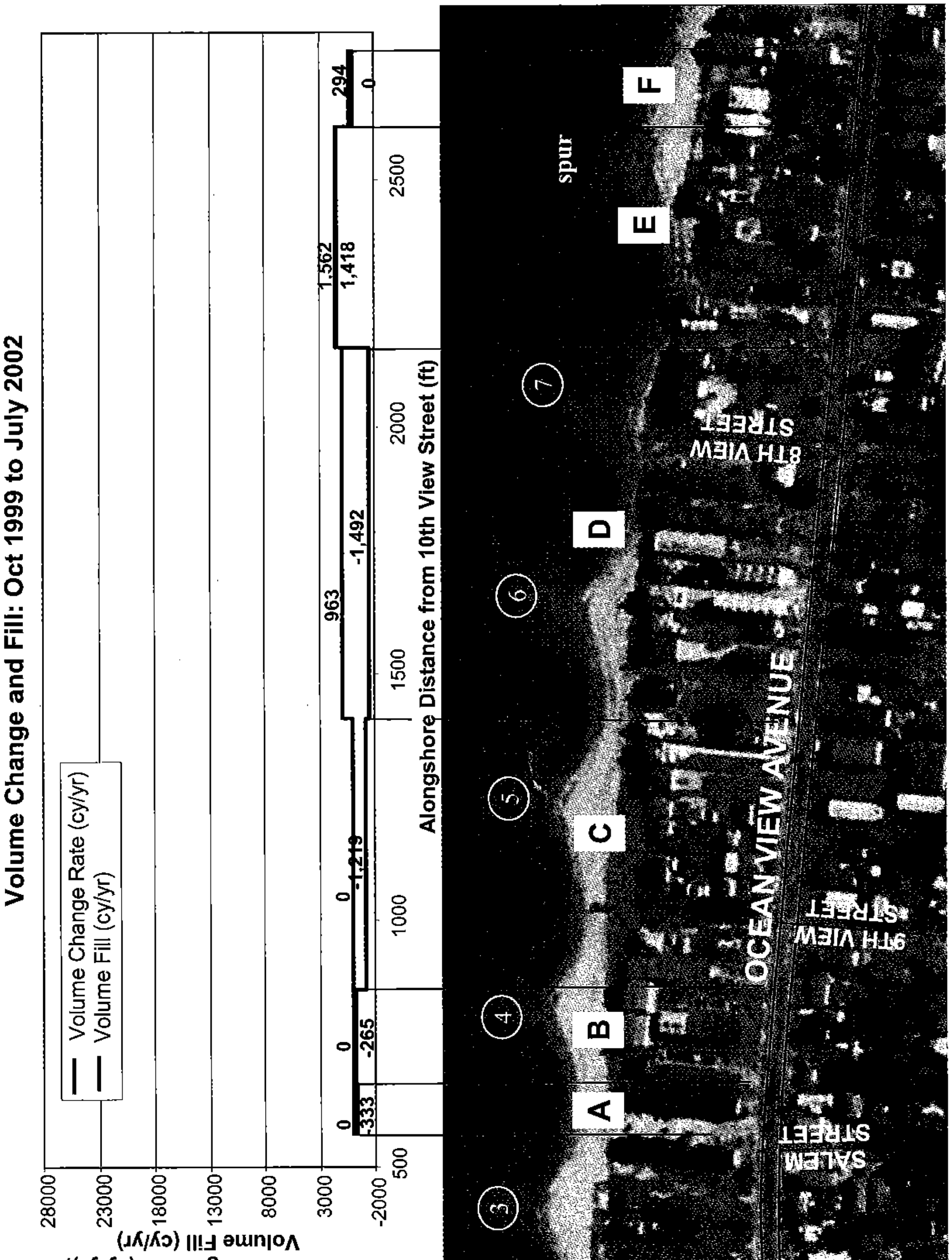


Figure III-19 Volume Change and Fill – Oct 1999 to July 2002

2. *July 2002 to April 2004*

This time period was analyzed using City survey data from July 2002 and Waterway data obtained in April 2004. The profile change and volume analysis was completed for six areas within the study area based on the available overlapping profile data. The offshore limits to which the profile changes were computed ranged from -14 to -16 ft NAVD88. **Figure III-20** shows the resulting volume change rates and volume fill rates across the study area for the July 2002 to April 2004 time period.

This July 2002 to April 2004 time period included the dune and beach fill project implemented in December 2003 in which approximately 36,000 cy of material was placed across the hotspot. In Area E, there was a net loss of 7,000 cy/yr. Approximately 70% of the material placed in this area remained during the time period in question. Despite some placement of material near the groin spur (Area F), the net volume change indicated mild erosion in this area. While the volume change analysis indicates a net loss of sediment across Areas E and F, recent site observations and further analyses to be discussed later in this report, indicate that the shoreline between breakwater 7 and the timber groin to the east has been stable or slightly accreting since the beach fill placement in December 2003. However, the portion of Area E west of breakwater 7 has suffered from lack of sediment transport and is eroding. The overall erosion indicated for Area E is a result of the lack of sediment transport from the east which has been minimized by the closing of the gap between breakwater 7 and the timber groin through construction of the spur and toe extension. Approximately 30% of material placed near breakwater 5 (Area D) remained in place. Again, this area experienced a net loss of sediment (approximately 3,000 cy/yr) due to the lack of sediment transport from the east. Finally, in Areas A and B, mild accretion occurred, despite the fact that no material was placed in these areas. In general the volume change trends occurring along the western portion of the study area indicate gradual westward transport of sediment from the eastern portion of the study area. This accretion is minimal and indicates that the shoreline has remained fairly stable across this western extent.

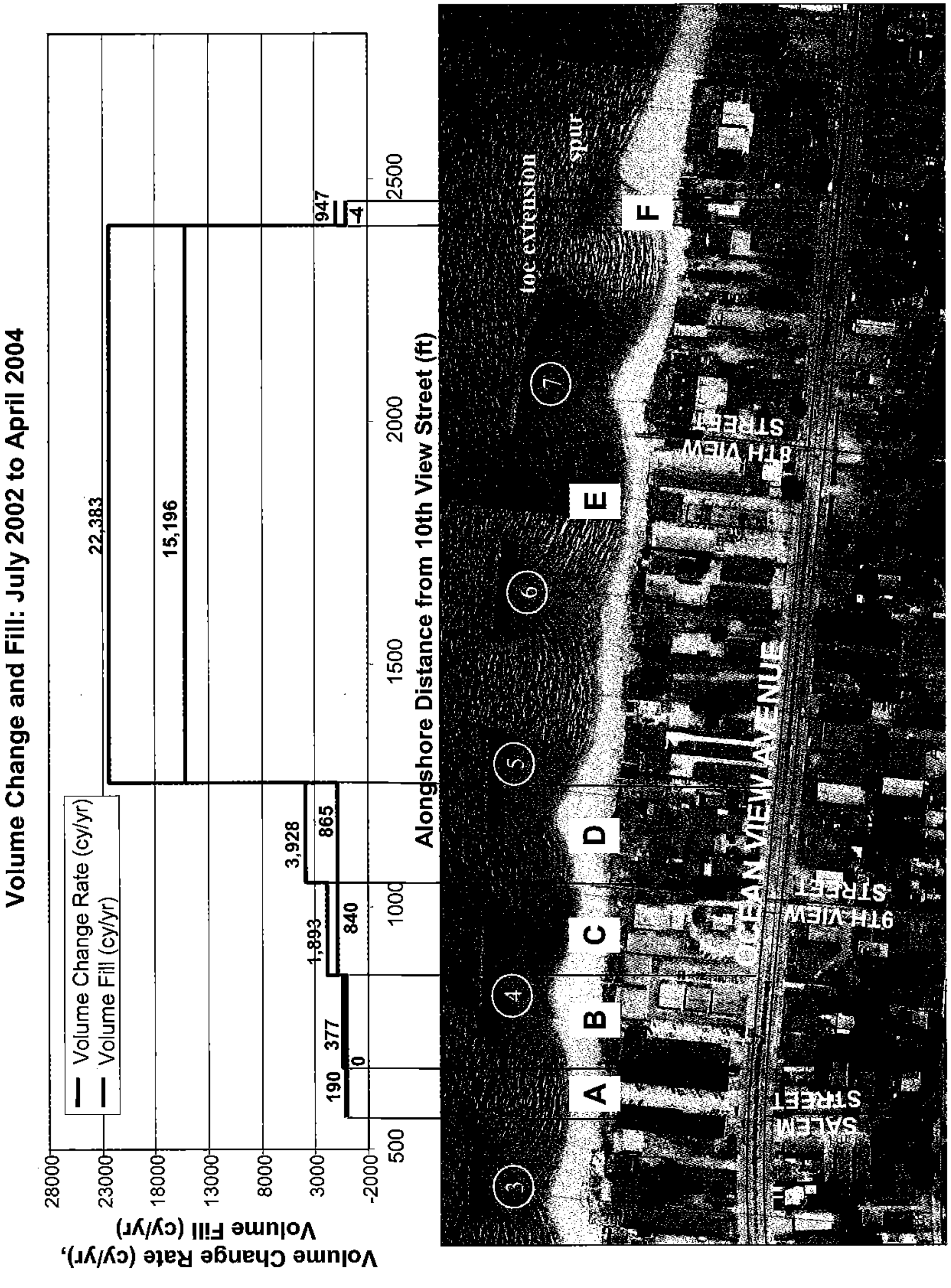


Figure III-20 Volume Change and Fill – July 2002 to April 2004

C. SUMMARY OF HISTORICAL DATA ANALYSIS

The review and analysis of historical data at the 800 Block study area proved to be a crucial aspect of this study, establishing historical shoreline change trends and the relation of these trends to engineering interventions at the project site. The significant findings of this analysis include:

- Prior to construction of breakwaters (1997-1998), general shoreline change shifted between periods of mild erosion/accretion (± 2ft/yr), but lack of a dune system and potential storm damage concerns necessitated action.
- Construction of the breakwaters resulted in accretion over a majority of the critical area, but removal of groins contributed to the existing erosional hotspot between breakwater 7 and the existing timber groin (at the site of the future groin spur). Numerous beach nourishment projects were implemented at this hotspot, but erosion persisted (avg -2.5 ft/yr).
- Following groin spur construction in December 1999, shoreline accreted landward of the spur, but continued to erode (avg -15 ft/yr) from breakwater 7 to tip of spur.
- The breakwater toe extension completed in May 2002 resulted in buildup of the tombolo behind breakwater 7. However, erosion of the shoreline occurred both east of the hotspot and west, gradually diminishing the salients behind the western breakwaters.
- Numerous beach nourishment projects have been completed at the hotspot (Dec 1998, Dec 1999, July 2001, Sept 2001, May 2002, Dec 2003), revealing that the hotspot has been an increasing problem despite structural modifications. Shoreline trends indicate that most material placed is being lost towards the west or offshore.

In general, M&N concluded that the hotspot is located at a unique position along the major bend in the Ocean View shoreline where the site is subject to increased sediment losses due to relative shoreline positions to predominant wave direction. With the numerous erosion control alternatives that have been implemented, the historical data reveals that longshore sediment transport may have been interrupted on an increasing basis with each structural modification. In particular, the timber groin adjacent to the rock spur was originally too long, blocking significant sediment transport from the east from this already naturally sediment starved area. The addition of the groin spur and breakwater toe extension only increased this blockage of transport

Based on the review of historical data, it would appear that a better transition would help mitigate these offshore losses and improve sediment transport from the east to the west. However, in order to fully test these alternatives, detailed modeling of the existing and proposed solutions would be required.

IV. MODELING OF SHORELINE CHANGE WITH GENESIS

GENESIS (Generalized Model for Simulating Shoreline Change) is designed to simulate long-term shoreline change based on spatial and temporal differences in longshore sediment transport induced primarily by wave action. The GENESIS modeling system allows for a number of user-specified inputs including wave inputs, initial shoreline positions, coastal structures and their characteristics, and beach fills; all of which aid in the calculation of sediment transport and shoreline change. This model was developed at the U.S. Army Corps of Engineers (USACE), Engineer Research and Development Center (ERDC), Coastal & Hydraulics Laboratory (CHL). For a more detailed description of the GENESIS model, the reader is referred to the User's Manual and Technical Reference published on the model (Hanson and Krauss, 1989, Gravens et al, 1991).

GENESIS-T is a recent release that expands on the modeling capabilities of GENESIS, allowing for the formation of tombolos at detached breakwaters and/or T-groins. Unfortunately, this model was still under development at the beginning of this study, and the demo release available at that time was reported to have known bugs in the explicit solution scheme. Therefore, to minimize uncertainty in the shoreline change modeling results, GENESIS was employed in this study of the 800 Block area.

GENESIS operates within the Coastal Engineering Design and Analysis System (CEDAS), a suite of tools developed by Veri-Tech, based on various numerical models and codes developed at CHL. GENESIS runs through NEMOS, which is designed to ease in the preparation of data inputs, analysis, and manipulation for a number of related coastal models.

The GENESIS model has potential for many applications in the coastal environment, including evaluation of longshore sediment transport, analysis of beach fill performance, or the analysis of the impact of coastal structures on shoreline change.

The main inputs to the GENESIS model include:

- Shoreline Position Data – one-dimensional description of the shoreline position relative to a straight baseline position,
- Wave Data – long-term time dependent description of wave heights, periods, and directions applicable to the study area,
- Coastal Structures – position and characteristics of coastal structures (breakwaters, groins, jetties, or seawalls) acting along the study area,
- Beach Fill – starting and ending dates and location of beach fill defined by an added berm width,
- Sediment and Beach Characteristics – effective grain size, average berm height, and closure depth for the study area,
- Sediment Transport Parameters – used to characterize longshore sediment transport and calibrate the model, and
- Boundary Conditions – seaward boundary conditions for the input wave data and lateral boundary conditions for the shoreline (left and right).

A. MODELING SCOPE

The GENESIS model served as the basis for developing an understanding of the historical sediment transport and erosional patterns along the 800 Block study area and for evaluating numerous erosion control alternatives. The scope of the GENESIS modeling task involved evaluating the long-term change in shoreline position based on a long-term period of wave action (1991-2004).

To establish the appropriate model parameters, the GENESIS model was calibrated for an October 1999 - April 2004 time period using historical shoreline positions and coinciding wave data. GENESIS is calibrated by adjusting the longshore sand transport coefficients (K_1 and K_2). Additionally, the model may be calibrated by adjusting the characteristic transmissivity or permeability of offshore breakwaters, groins or jetties.

Once a calibrated model was developed, the model was run for a number of conditions using the established calibration coefficients. First, the model was used to investigate pre-construction conditions to verify that the model reproduced the erosional hotspot just east of 8th View Street that originally warranted the construction of the groin spur and successive erosion control projects. Next, an existing conditions model was developed and run for a future 13-year time period to determine the impacts with no mitigation of the existing erosion problem. Finally, the calibrated model was used to simulate future long-term shoreline change with numerous erosion control alternative improvements in place. The selected erosion control alternatives were evaluated based on comparisons against the predicted existing shoreline.

GENESIS employs an implicit computational scheme which does not allow tombolo formation. Therefore, the model will cease if the predicted shoreline position attaches to a breakwater at any point during the simulation. The existing conditions model run, which is discussed in detail in **Section IV.E**, was terminated after 8-years due to tombolo formation. Therefore, for the purposes of presentation and comparison of GENESIS model results for the pre-construction, existing conditions, and proposed alternatives model runs, the predicted 8-yr future shoreline position will be presented.

B. STUDY AREA

The GENESIS model extended from approximately 11th View Street to 6th View Street, which includes the entire breakwater field and adjacent groins to the east. **Figure IV-1** shows the GENESIS model extent and structure locations. The structure numbering and naming convention shown in this figure will be referenced throughout the remainder of this report. This model extent was originally larger, extending from Willoughby Spit at the west end to approximately 1st View Street at the east end. However, once modeling began, it was determined that the curvature of the shoreline on the east and west ends of the model was too great to yield results that represented the historical shorelines in the calibration model. Therefore, the model extent was shortened to include only those structures in the hotspot area and adjacent structures that may be altered in the alternative model runs.

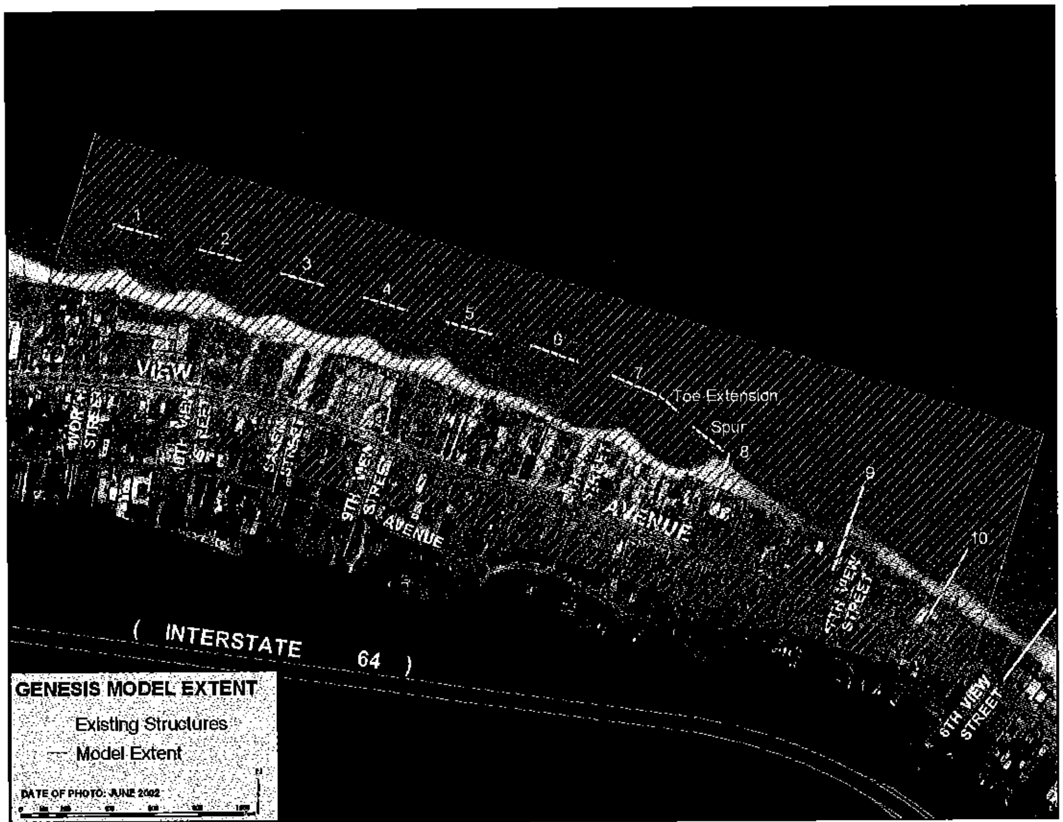


Figure IV-1 GENESIS Model Extent and Existing Structure Locations

C. CALIBRATION MODEL

The GENESIS model was calibrated to reflect the historical trends of longshore sediment transport and resulting shoreline change over the study area. The overall calibration time period was based on the availability of quality measured shoreline data and coincident transformed wave data. An overall calibration time period was selected, and sequential modeling time periods were defined such that the structural conditions on the beach were consistent during the course of each model time period. This was necessary as GENESIS does not allow for time-varying structural configurations in an individual model (i.e. structures are either present or absent). The relevant shoreline data, in conjunction with key construction dates of engineering projects at the project site, became the basis for setting up the time periods for the subsequent calibration models. **Table IV-1** reflects the four subsequent models used in the calibration process along with key engineering projects which were implemented during each time span.

Table IV-1 GENESIS Model Calibration Time Periods

MODEL	Dates	KEY ENGINEERING PROJECTS
1	Oct 1999 – Dec 1999	None
2	Dec 1999 – Oct 2001	Dec 1999: groin spur construction Dec 1999: beach nourishment (1,000 cy) July 2001: beach nourishment (500 cy) Sept 2001: beach nourishment (2,000 cy)
3	Oct 2001 – May 2002	None
4	May 2002 – April 2004	May 2002: toe extension construction on breakwater 7 May 2002: removal of groin seaward of spur May 2002: beach nourishment (3,438 cy) Sept 2003: beach nourishment (1,000 cy) Dec 2003: beach nourishment (39,800 cy)

GENESIS is typically calibrated by adjusting the sediment transport parameters, K_1 and K_2, which characterize longshore sediment transport across the region. If structures are present, the calibration process may also involve adjustment of the transmission coefficients for breakwaters, and the permeability coefficients for groins until an accurate shoreline response is achieved. Several other boundary condition parameters (e.g. smoothing, wave input adjustments) may be tweaked to achieve a particular shoreline response, or to test the model sensitivity. For this study, the general calibration procedure involved:

1. establishing known model inputs including shoreline position, waves, locations of structures, sediment and beach characteristics, and boundary conditions
2. establishing initial sediment transport parameters and adjusting these parameters until the relative shoreline response (erosion/accretion) matched historical trends, and
3. working in the direction of sediment transport (east to west), adjusting the groin permeability and breakwater transmissivity coefficients until the shoreline response (e.g. updrift/downdrift, and salient/embayment formations) matched historical trends.

This calibration sequence was followed using known inputs and initial parameters based on the East Ocean View study. Then, particular input parameters (sediment transport parameters, smoothing, wave input adjustments etc.) were revisited and the sensitivity of the model response to changes in these parameters was tested. In many cases, a given parameter was adjusted to yield a more accurate shoreline response. The final determined input data for the calibration model will be presented in the following sections, in the order that this information is input to the GENESIS model (e.g. not the true calibration sequence).

1. Shoreline Position Data (Calibration Model)

For shoreline input, GENESIS requires the shoreline be specified in a station-offset formulation whereby the station represents a position along a landward baseline and the offset is the perpendicular distance from this baseline to the shoreline. The initial shoreline used in the GENESIS model was the October 1999 shoreline, digitized from aerial photos of the study area. The final reference shoreline to which the model was calibrated was the April 2004 shoreline, which was the MHW contour (+0.91 ft NAVD88) obtained from a DTM built using the measured beach profile surveys. The initial shoreline in each intermediate model was the final predicted shoreline from the previous model. During the intermediate model time periods, the predicted final shorelines were also checked against measured shoreline positions (reference shorelines), where available. **Figure IV-2** shows the shorelines, initial and reference, used in the GENESIS model calibration runs overlain on the June 2002 aerial photograph.

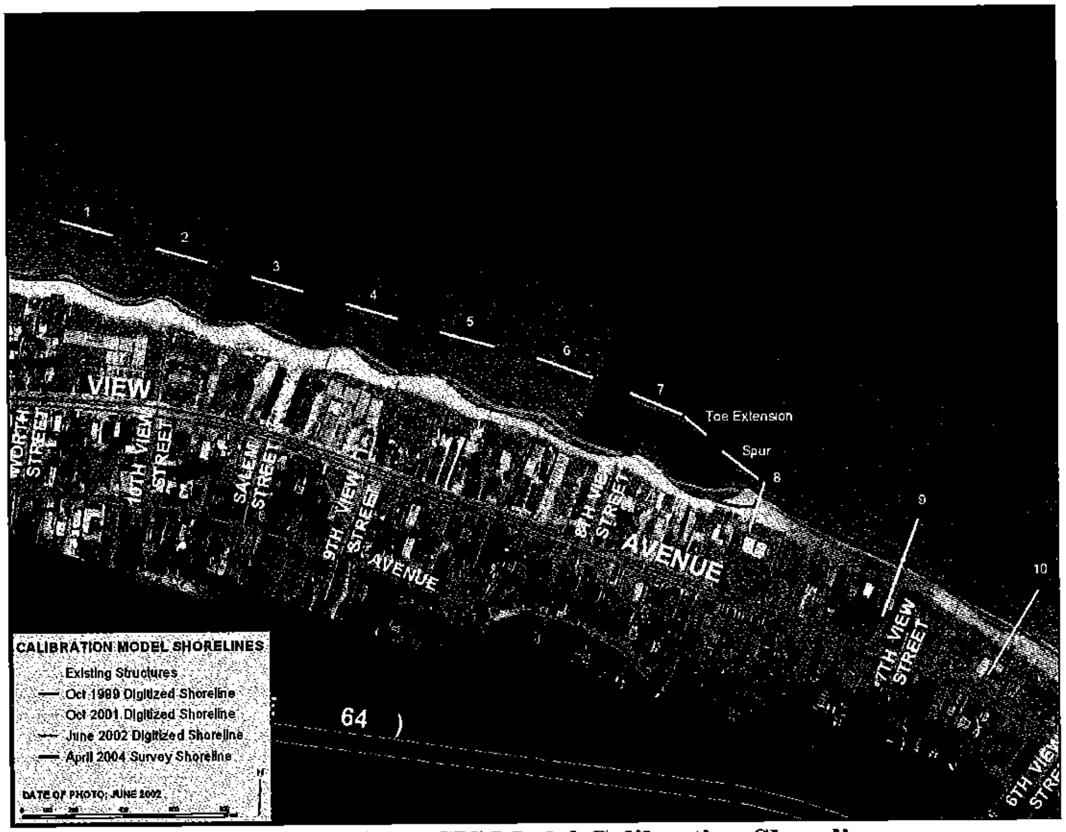


Figure IV-2 GENESIS Model Calibration Shorelines

2. *Wave Data (Calibration Model)*

The wave data used in the GENESIS modeling was applied using an external wave model which transformed the sea and swell time series uniquely to various nearshore locations along the study area. The application of varying nearshore wave conditions was necessary in this study, given the unique position of the study area along the overall shoreline bend and the shallower bathymetry towards the west. Based on the previous wave refraction modeling completed for the East Ocean View study using MIKE 21 NSW, the variation in the wave height refraction coefficients and the refracted wave directions along the 800 Block study area extent was significant. The wave data and associated methodologies used to develop the nearshore refraction data is discussed in detail in the East Ocean View report (M&N, June 2004). The application of this wave data in the present study is summarized below.

To apply the varying nearshore wave conditions in the GENESIS model, the offshore (untransformed) swell and sea time series were specified as model input. The offshore swell and sea time series represented the measured Duck FRF data which was transformed to deepwater and back-refracted to an offshore position using the straight and parallel method outlined in the USACE's Coastal Engineering Manual (CEM). This wave data was at a water depth of approximately -36 ft NAVD88.

To transform the offshore data to the study area, refraction data for a range of wave conditions at various nearshore locations were specified. The nearshore locations at which refraction data were specified were located approximately every 1000 ft along the study area extent at a water depth of approximately -20 ft NAVD88. The refraction data included the wave height refraction coefficients and the refracted wave directions which were obtained from the MIKE 21 NSW model output for conditions of wave periods greater than 5.5 seconds (swell waves) and computed based on fetch ratios between the Duck and nearshore project locations for conditions of wave periods less than 5.5 seconds (sea waves).

The GENESIS model used the defined refraction data as a lookup table to transform a given wave condition from the offshore to the nearshore. Then, an internal wave model was applied in GENESIS to bring the nearshore waves to the breaking point.

For the calibration model, the offshore swell and sea wave data components were extracted for all four model time periods: 1) Oct 1999 to Dec 1999, 2) Dec 1999 to Oct 2001, 3) Oct 2001 to May 2002 and 4) May 2002 to Apr 2004. These data were applied along with the nearshore refraction data to simulate the applicable wave conditions for each time period.

3. Coastal Structures (Calibration Model)

GENESIS requires the locations and characteristics of nearshore structures as input. The coastal structures are incorporated in the GENESIS model by a station-offset formulation, similar to the shoreline position. Allowable structures include non-diffracting groins/jetties, diffracting groins/jetties, seawalls, and/or detached breakwaters. Each structure is modeled uniquely with respect to longshore transport and shoreline change. In general, structures exert two direct effects on the shoreline change modeling:

1. Structures extending into the surf zone block a portion, or all, of the longshore transport from their updrift sides and may reduce the transport of sand towards the downdrift side. This effect may be induced by a groin or jetty.

2. Structures which have seaward ends extending well beyond the surf zone, including jetties or detached breakwaters, induce wave diffraction which causes the local wave height and direction to change.

For the four sequential calibration models, the coastal structures present during each model time period were implemented. **Figure IV-3**, **Figure IV-4**, and **Figure IV-5** present the structural configuration implemented in each model. (Note: Calibration Model 3 has the same structure configuration as Calibration Model 2.)

Figure IV-3 Calibration Model 1 – Oct 1999 to Dec 1999 – Structural Configuration

Figure IV-4 Calibration Models 2 & 3 – Dec 1999 to May 2002 – Structural Configuration

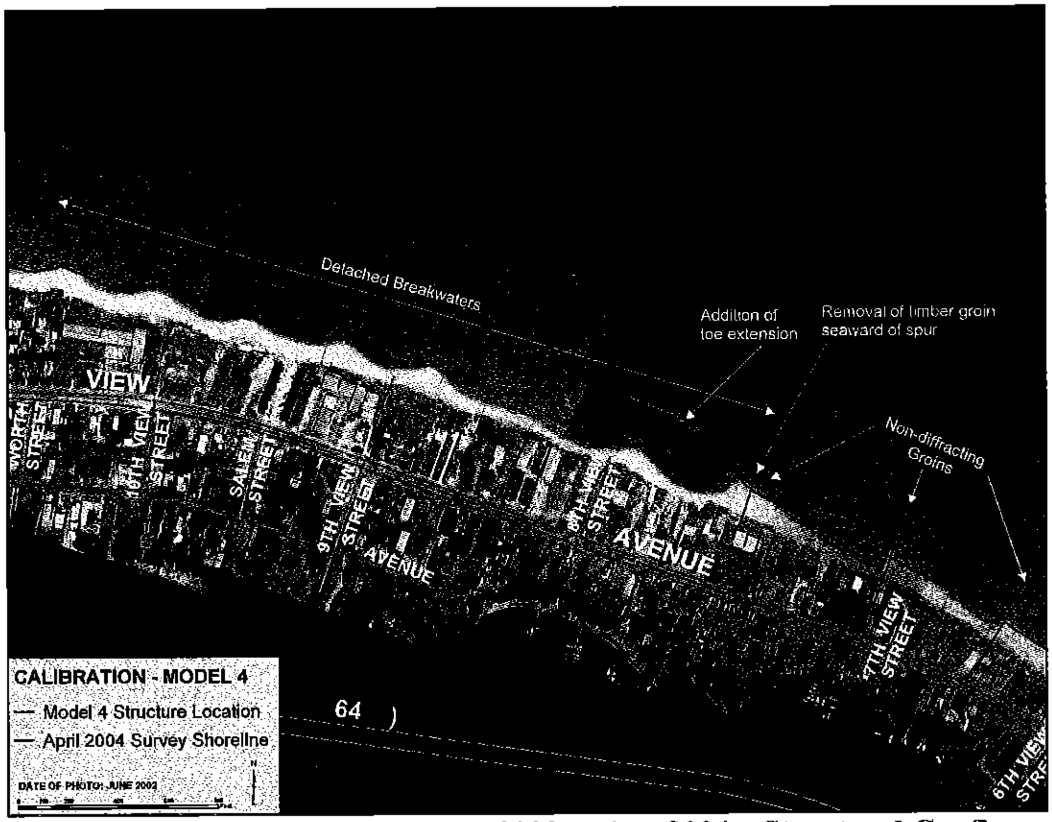


Figure IV-5 Calibration Model 4 – May 2002 to Apr 2004 – Structural Configuration

Wave transmission through and over breakwaters is controlled by the user-specified transmission coefficient (Kt). The transmission coefficient is defined as the ratio of incident wave heights on the shoreward side of the breakwater to the wave heights on the seaward side of the breakwater and may range from 0 (no transmission) to 1 (complete transmission). Transmission coefficients applied in the 800 Block model were determined through numerous model iterations, in which the Kt value for each detached breakwater was adjusted for a given set of longshore transport rate coefficients until the observed shoreline response matched closely with historical trends. The breakwaters incorporated in the calibration models are known to be moderately to highly porous with low crest elevations (+2 ft NAVD88), yielding transmission coefficients ranging from 0.6 to 0.75 (60% to 75% wave transmission through and over the structure).

Similar to detached breakwaters, a non-diffracting or diffracting groin implemented in GENESIS must have a defined permeability which controls the transmission of sand over and through the structure. The permeability can range from 0, implying an impermeable structure to 1, implying a completely transparent structure. The permeability of the existing groins incorporated in the model were adjusted beginning with the easternmost groin and moving westward, with the direction of sediment transport until the observed shoreline response on the updrift and downdrift sides of the groin matched closely with historical trends. The existing timber groins present on the eastern end of the model extent were modeled as non-diffracting groins since they do not extend far enough beyond the surf zone to induce wave diffraction. The permeability coefficients were set at 0.5, 0.3 and 0.2, respectively from the easternmost groin to the westernmost groin at the spur.

4. Beach Fill (Calibration Model)

Beach fill can be incorporated in GENESIS by defining a starting and ending date, spatial extent, and added berm width for the project. GENESIS places the fill by advancing the shoreline position by a unit width per time step across the defined spatial extent. Six beach fill projects were implemented in the calibration models. The added berm width for each project was calculated based on the following methodology derived from USACE (2002).

$$Added\ Berm\ Width\ (ft) = \left(\frac{V_{fill}}{L_{fill} * D_{active}} \right), \text{ where}$$

V_{fill} is the volume of fill (ft^3),
L_{fill} is the fill length, and
D_{active} is the active depth (average berm height plus depth of closure). For this work the active depth was assumed as 10 ft, considering an average berm height of +3 ft and closure at -7 ft.

The assumed beach fill volumes and lengths and the calculated added berm widths for those projects included in the calibration models are presented in **Table IV-2**.

Table IV-2 Beach Fill Parameters in GENESIS Calibration Models

Date	Volume (cy)	Extent (ft)	Added Berm Width (ft)
Dec 1999	1,000	200	14
July 2001	500	175*	8
Sept 2001	2,000	300	18
May 2002	3,438	300	31
Sept 2003	1,000	350	8
Dec 2003	39,800	1,260	85

*extent assumed based on approximate placement location (see **Table II-4**)

5. Sediment and Beach Characteristics (Calibration Model)

The selected effective grain size (d50) assumed in the GENESIS model was 0.40 mm. This grain size was determined based on analysis of measured sediment data collected near the study area in April 2004 as detailed in **Section II.E**. As stated previously, the use of this characteristic grain size is supported by historical measurements which cite coarse grain sizes ranging from 0.4 to 0.5 mm between Willoughby Spit to Central Ocean View (Waterway Surveys and Engineering, 1984).

The average berm height was defined as +3 ft NAVD88 and the closure depth was set to -7 ft NAVD88. These values were determined based on observations of measured survey data during the calibration time period.

6. Sediment Transport Parameters (Calibration Model)

Longshore sediment transport is characterized by the transport parameters K_1 and K_2 in GENESIS. The transport rate coefficient, K_1, is used to control the time-scale and magnitude of the simulated shoreline change, while K_2 is used to control shoreline change and longshore sand transport in the vicinity of structures. Although the values of K_1 and K_2 have been empirically estimated, these coefficients are treated as calibration parameters in GENESIS.

The calibration models were initially run with the K_1 and K_2 coefficients used in the East Ocean View study (M&N, June 2004), where $K_1 = 0.25$ and $K_2 = 0.18$. The resulting April 2004 model shoreline was compared with the measured April 2004 shoreline and the coefficients were adjusted to achieve the closest match in the model results and the measured shoreline position. Through this procedure, it was determined that reducing the K_1 value and increasing the K_2 value resulted in shoreline response which was most indicative of historical patterns. The final calibration coefficient values were $K_1 = 0.10$ and $K_2 = 0.30$.

*7. **Boundary Conditions (Calibration Model)***

The required boundary condition inputs for GENESIS include the seaward wave data boundary conditions and the lateral boundary conditions at the left (west) and right (east) ends of the shoreline.

a) Seaward Boundary Conditions

As stated, two wave components, swell and sea, were implemented in the GENESIS model. Within the seaward boundary conditions, the user may modify the input wave conditions (wave height and direction) to analyze the impact modeled wave conditions have on the resulting shoreline response. Since the wave data utilized in this study were derived from measured wave conditions at the Duck FRF in NC, the sensitivity of the model to the given wave conditions was evaluated by applying adjustment factors to the wave heights and wave directions.

After numerous model runs utilizing the original, refracted wave data, it was noted that subtle modifications to both wave heights and directions further improved model results. Given that the base wave data was derived from Duck, NC, it was felt that these slight modifications were warranted and justified.

The smoothing factor applied with the seaward boundary conditions is an indication of how the offshore contour moves relative to the shoreline and is used to prevent unrealistic wave transformation that may occur if the shoreline changes relatively abruptly (e.g. at a groin). The smoothing value may range from 0 to 50, with a lower value indicating the offshore contour follows the shoreline position and a higher value implying that the contour is straighter than the shoreline. After numerous trials, a smoothing factor of 20 was applied in the GENESIS model based on the effect that this parameter was observed to have on the resulting shorelines.

b) Lateral Boundary Conditions

The left (west) and right (east) boundaries of the model were located at fairly stable shoreline positions which were far enough from the hotspot, so as not to influence sediment transport in these areas. There were no existing or proposed structures (i.e. groins or jetties) adjacent to or crossing the left and right boundaries and the shoreline position at both boundaries was considered stable. Therefore, these boundaries were defined as pinned, indicating that these shoreline positions should not change during simulations.

8. Calibration Model Results

Figure IV-6 shows the final shoreline resulting from the GENESIS calibration modeling against the initial shoreline position (Oct 1999) and the comparable measured shoreline position (April 2004).

As shown, the model output matches reasonably well with the measured April 2004 shoreline. Based on these results, all future model runs utilized the defined parameters for coastal structures (breakwater transmission and groin permeability), sediment transport (K_1 and K_2), and boundary conditions (wave height change factor, wave angle offset, and smoothing factor) which were set during the calibration modeling.

D. PRE-CONSTRUCTION MODEL

The calibrated GENESIS model was used to evaluate the predicted shoreline response under the conditions which existed prior to construction of the groin spur in December 1999. The objective of this analysis was to verify that the model reproduced the erosional hotspot, downdrift of groin 8 that originally warranted the construction of the groin spur and successive erosion control projects. This model run simulated the response of the shoreline for a 13-year time period and will be referred to as pre-construction herein.

The initial shoreline used in the pre-construction model was the final shoreline from the calibration model run. Even though this shoreline was not representative of pre-construction site conditions, the goal of the modeling was to reproduce the general historical erosional patterns. The coastal structures which were present prior to construction of the groin spur in December 1999, were included in the GENESIS model. The wave data used in this GENESIS model consisted of the full 13-yr (1991-2004) offshore swell and sea time series. As described, this data was transformed to numerous nearshore locations by application of an external wave model in GENESIS which involved specifying refraction data for a range of offshore wave conditions at each unique nearshore location. All other parameters used in the GENESIS model were the same as defined for the calibration model including the structural characteristics, sediment and beach characteristics, sediment transport coefficients, and boundary conditions. There were no beach fill projects implemented in this model run.

Figure IV-7 shows the structural configuration implemented in this model run and the predicted shoreline position after an 8-year time period. As stated previously, the predicted 8-yr shoreline position was selected for presentation and comparison of GENESIS model results, because the existing conditions model run (discussed in the following section) was terminated due to tombolo formation immediately after 8 years of simulation. The final calibrated shoreline position which was the initial shoreline in this and all future model runs is included as a reference position.

The results of the pre-construction GENESIS model run show increased erosion over time west of groin 8, at the site of the future spur. In addition, the tombolos westward appear to have gradually diminished after 8-years of wave action. Therefore, it can be concluded that the GENESIS model reproduced the development of the erosional hotspot which warranted the previous erosion control projects.

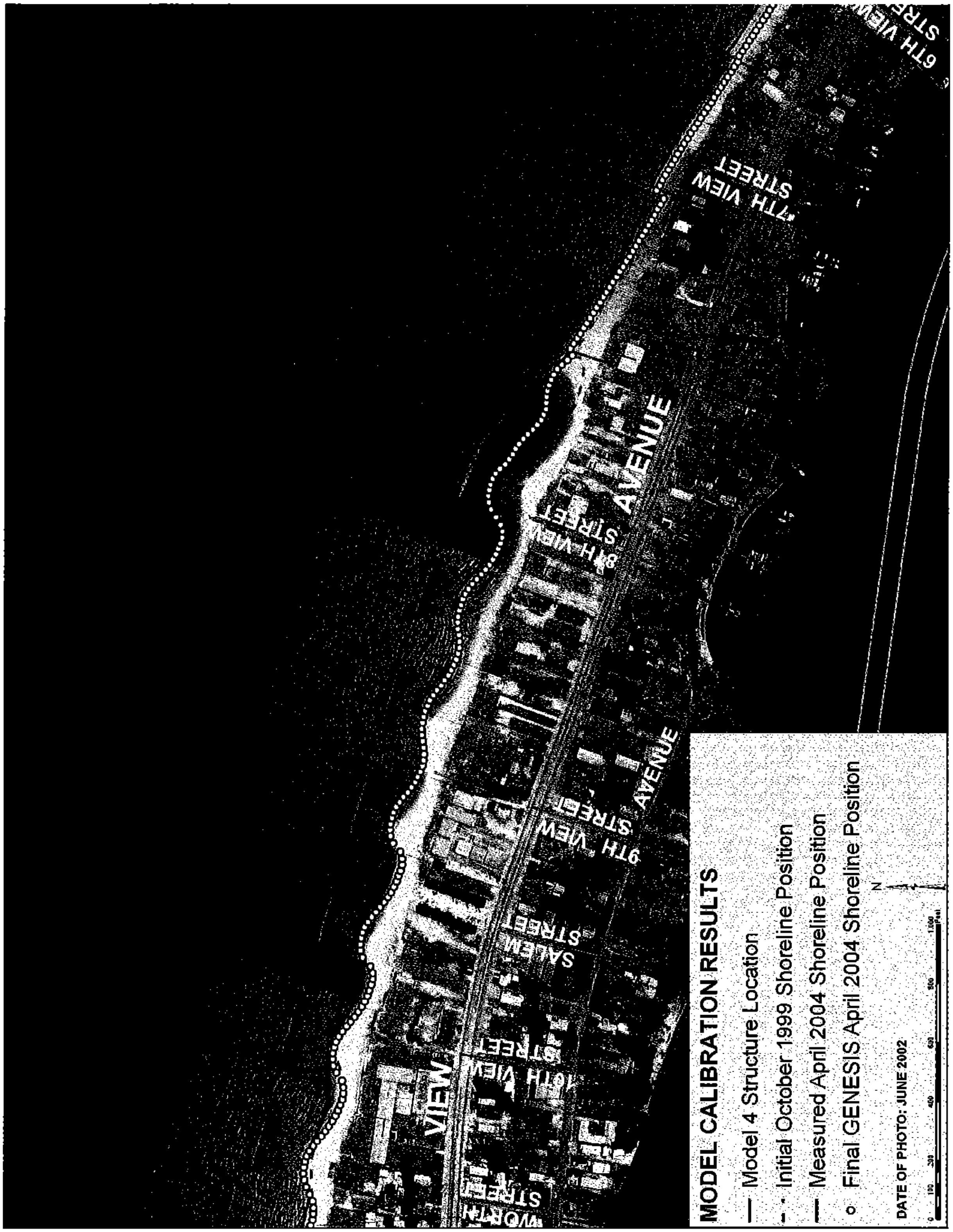


Figure IV-6 GENESIS Calibration Model Results

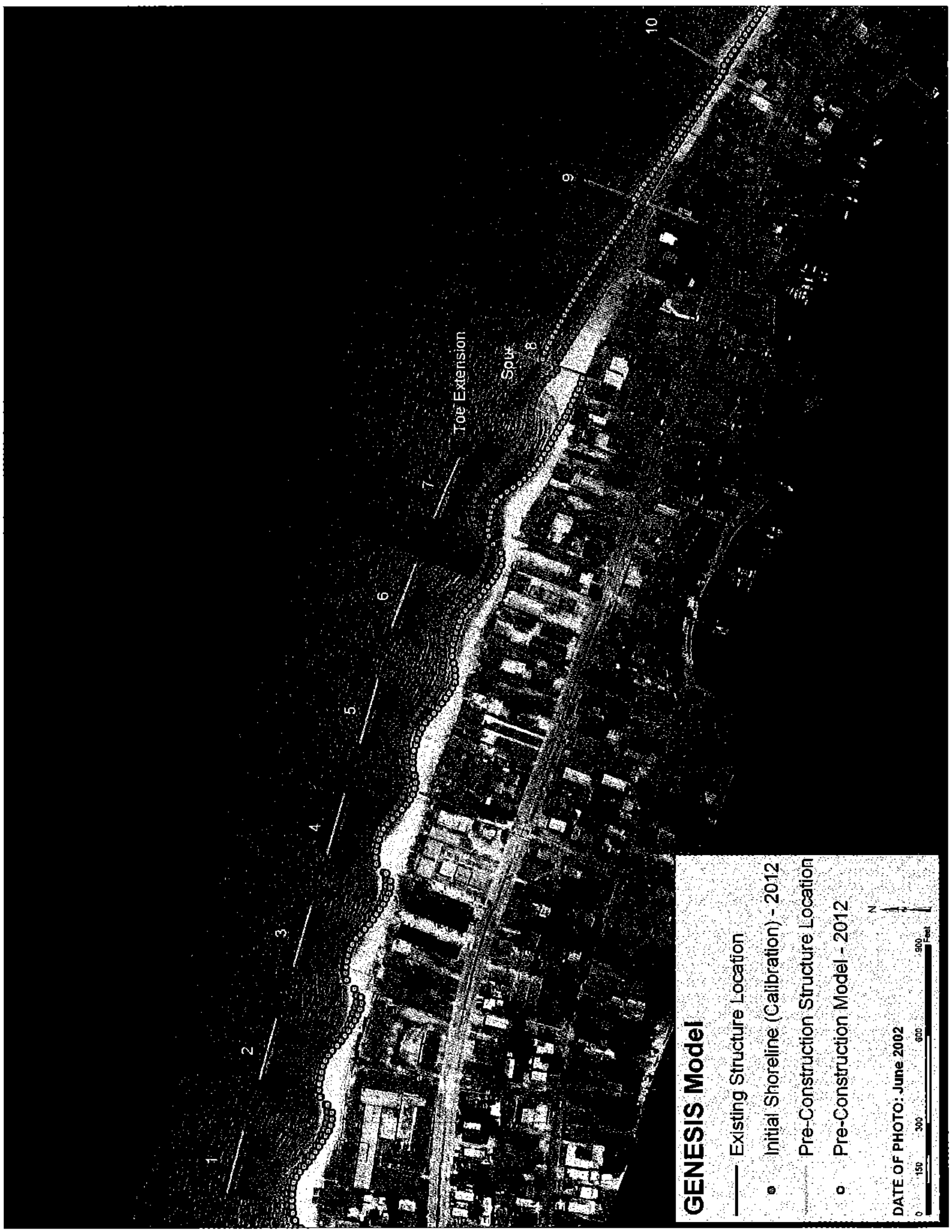


Figure IV-7 Pre-Construction GENESIS Model Results

E. EXISTING CONDITIONS MODEL

An existing conditions model was run to determine the impacts on the study area with no mitigation of the existing erosion problem. This model also served as the basis for decision making and comparison of proposed erosion control alternatives. The existing conditions model run involved a 13-yr simulation representing the predicted future response of the shoreline under long-term typical wave action. As in the pre-construction model run, the full 13-yr offshore swell and sea time series were transformed within GENESIS to numerous nearshore locations, utilizing refraction data. The initial shoreline in the existing conditions model was the final shoreline from the calibration model. This shoreline position matched closely with the measured April 2004 shoreline as shown previously in **Figure IV-6.** The existing structural configuration at the 800 Block was implemented in this model. All other parameters in the GENESIS model were the same as defined for the calibration model including the structural characteristics, sediment and beach characteristics, sediment transport coefficients, and boundary conditions. There were no beach fill projects implemented in this model run.

Figure IV-8 shows the structural configuration implemented in this model run and the predicted shoreline position after an 8-yr time period. The resulting shoreline is compared against the initial shoreline position.

As shown, the relative differences between the initial and predicted 8-yr shoreline positions indicate slight buildup of the salient behind breakwater 7 and the toe extension. To the east, the historical hotspot location shows slight accretion. However, to the west the results indicate that the salients are gradually diminishing and there is increased erosion in the embayments between the western breakwaters. This trend is consistent with shoreline change that has been observed recently at the 800 Block site. It should be noted that this behavior has also been influenced by the beach fill project which was implemented in December 2003 across the study area extent. Therefore, it can be concluded that the added fill along with existing erosion control structures have reduced the rate of erosion at the historical hotspot by blocking sediment transport from the east and locking the improved beach in place. However, the blocking of sediment transport has increased the rate of erosion to the west of breakwater 7 where a new hotspot has developed.

Figure IV-9 shows the 8-yr existing conditions model result compared against the 8-yr pre-construction model result along with the structural configurations implemented in both models.

The relative difference in the shoreline positions between the pre-construction and existing conditions model runs indicates that the structural erosion control efforts implemented to date (spur, toe extension, and shortening of groin 8) have improved the conditions at the hotspot by locking the beach in place. However, the addition of these structures has caused blocking of sediment transport from the east. Therefore the relative shoreline positions show minimal improvement west of breakwater 7, where a new erosional area of concern has developed (see **Figure IV-8**).

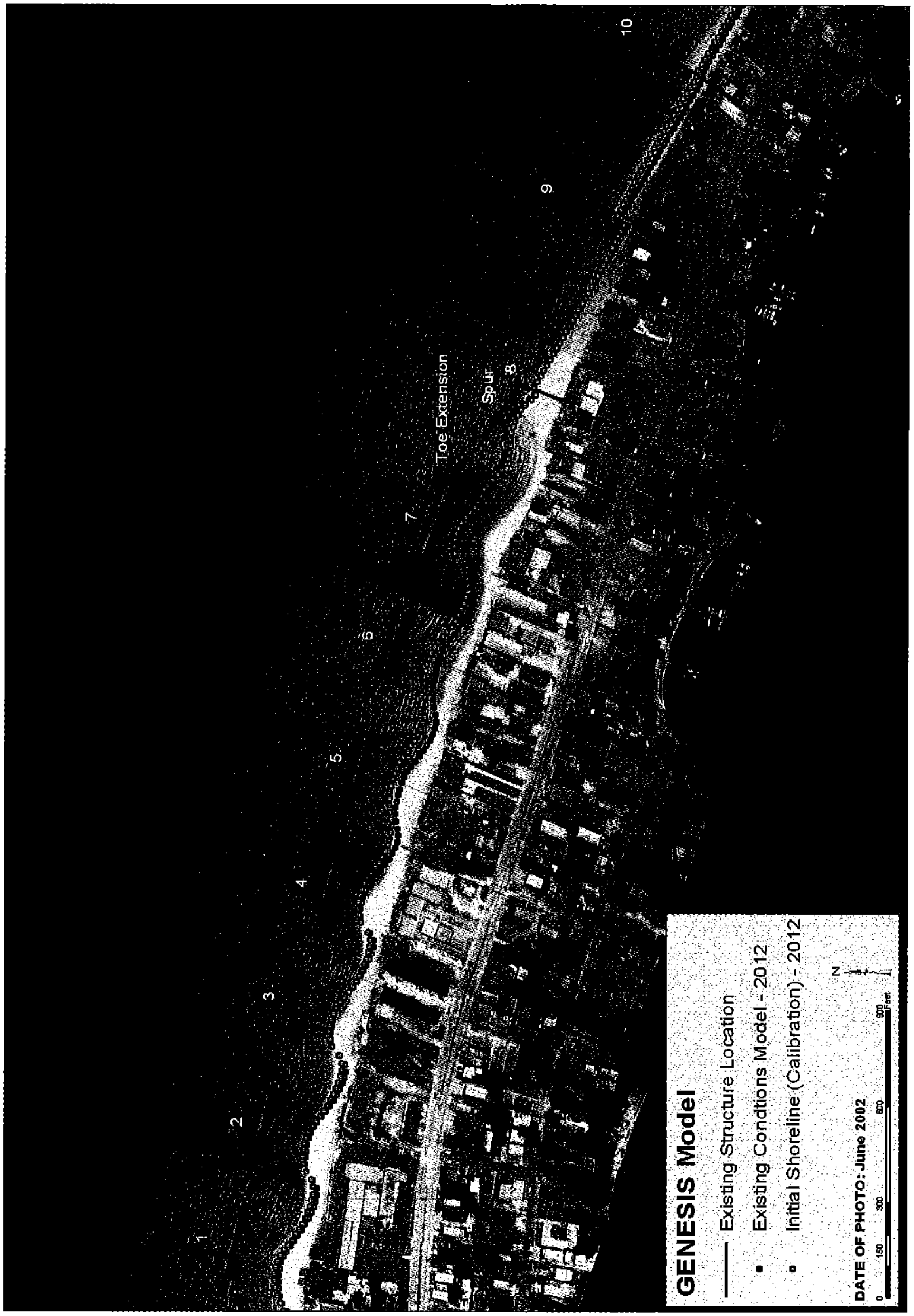


Figure IV-8 Existing Conditions GENESIS Model Results

Figure IV-9 Existing Conditions Vs. Pre-Constructions GENESIS Model Results

F. DEVELOPMENT OF EROSION CONTROL ALTERNATIVES

The review of historical data at the 800 Block study area (see **Section III**) revealed that the persistent erosion at the hotspot is largely dependent on the structural modifications that have been implemented in recent years. In addition, it was concluded that the general location of the hotspot along a protruding shoreline bend makes the area vulnerable to wave action and consequential erosion problems. The results of the existing conditions model indicate that the recent erosion control structures (groin spur and breakwater toe extension) have further closed the gap between breakwater 7 and the timber groin, reducing sediment transport to areas west. With the beach fill placement implemented in December 2003, the shoreline has been further locked in place along the hotspot. However, the reduction of sediment transport within the historical hotspot has caused a new erosion hotspot to develop west of breakwater 7.

Given these conclusions, the goal of the proposed erosion control alternatives is to improve the overall transition at the 800 Block study area and induce a more uniform shoreline response along the study area. Proposed options for improving the structural transition generally involved opening the gap near the present groin spur and toe extension to increase sediment transport to, and westward of, this area while still trying to stabilize and protect the area and lock the beach in place.

In September 2004, a meeting was held with the City and M&N to present the preliminary results of the historical data review and analysis and to discuss initial proposed alternatives for erosion control at the hotspot. The preliminary erosion control alternatives which were presented by M&N included the following structural modifications, improvements, and additions, to be implemented individually or in combination, where practicable:

- Remove rock spur
- Remove toe extension on breakwater 7
- Realign breakwater 7 toe extension to make it parallel with breakwater 7
- Move existing rock spur offshore and/or realign and lengthen to form new breakwater
- Add low-crested shore perpendicular groins in immediate hotspot areas between existing breakwaters

In response to the above alternatives and the evidence presented as part of the review of historical data, the City made additional requests for structural configurations to be modeled which included:

- Shorten existing groin(s) including the timber groin adjacent to the rock spur and the timber groin directly east
- Add new breakwater(s) east of the existing groin spur

In addition to the above mentioned alternatives, M&N proposed that immediate and periodic beach nourishment will be necessary to maintain a stabilized shoreline. Given the historical behavior at the site and its location at the shoreline bend, it is felt that this area will always require beach nourishment. However, with an improved transition it is hoped that the magnitude and frequency of nourishment could be reduced from existing conditions.

G. MODELING OF PROPOSED ALTERNATIVES

The calibrated GENESIS model was used to simulate future long-term shoreline change with numerous erosion control alternative improvements in place. The modeled erosion control alternatives involved removal and/or modification of existing structures and/or addition of new erosion control structures (i.e. breakwaters or groins).

Each proposed structural configuration was modeled in GENESIS for a future 13-yr time period utilizing the swell and sea wave data time series. The initial shoreline was the final shoreline position from the calibration model which matched closely with the measured April 2004 shoreline. The characteristic transmissivity and permeability of existing structures were set based on the defined values determined in the calibration model. The estimation of these parameters for new, proposed structures will be discussed for the applicable options presented herein. All other parameters in the GENESIS model were the same as defined for the calibration model including the sediment and beach characteristics, sediment transport coefficients, and boundary conditions. There were no beach fill projects implemented in the modeling of proposed alternatives.

A number of selected alternatives will be presented herein, providing an overview of the range of alternatives analyzed and to present the process of optimization used to determine the final proposed alternatives. The first three options present alternatives which involve removal of structures with or without shortening of existing groins. Therefore, the first three reviewed options (Options 1, 2, and 3) would only involve demolition and no new construction. The latter six options (Options 4a, 4b, 5, 6, 7, and 8) involve removal of existing structures along with construction of new breakwaters and in Option 8, the addition of short, low-crested groins in the breakwater embayments.

Each selected erosion control alternative was evaluated through comparison of the predicted future 8-year shoreline position determined from the existing conditions model and the predicted 8-year shoreline position with comparable alternatives in place. As stated previously, the predicted 8-yr shoreline position was selected for presentation and comparison of GENESIS model results, because the existing conditions model run (discussed in the previous section) was terminated due to tombolo formation immediately after 8 years of simulation. Two final alternatives were selected and recommended for additional hydrodynamic modeling using Delft3D. For ease in the presentation of results, all figures referenced in the following discussions are included at the end of this **Section IV.G**.

1. Option 1

Option 1 involves removal of the toe extension on breakwater 7. The existing groin 8 is to remain shortened as done in May 2002 and the spur is to remain in place. **Figure IV-10** shows the structural configuration implemented in this model run and the predicted shoreline position after an 8-yr time period. The resulting shoreline is compared against the existing conditions model shoreline position after an 8-yr time period.

Based on the model results, this option allows more sediment transport to reach the salients and embayments to the west of the hotspot and reduces the erosion in this area. The results indicate that the shoreline to the east of groin 8 may retreat slightly in comparison to the existing conditions configuration. This is likely due to the fact that opening of the gap between breakwater 7 and the existing spur allows for increased sediment transport from this area towards the hotspot and western breakwater field.

2. *Option 2*

Option 2 is a variation on Option 1 in which groin 8 is shortened by an additional 100 ft from the existing length, moving the tip further landward of the spur. **Figure IV-11** shows the structural configuration implemented in this model run and the predicted shoreline position after an 8-yr time period. For comparison, the 8-yr shoreline is also shown for Option 1 and the existing conditions model.

Relative to Option 1, the predicted future shoreline position for Option 2 is significantly further seaward than Option 1 on the west side of groin 8, but is significantly landward than Option 1 on the east side of this groin. Based on these results, it can be concluded that the increased sediment transport that occurs as a result of shortening groin 8 behind the spur causes increased shoreline retreat on the updrift side of the groin. In general, the added downdrift benefit of Option 2 does not outweigh the potential negative impacts on the updrift side of the groin.

3. *Option 3*

Option 3 involves removal of the toe extension and groin spur. Groin 8 is to remain at its existing length. This option is very similar to the pre-construction conditions, with the exception that groin 8 is shorter by approximately 115 ft. Modeling of this option evaluates whether initial shortening of groin 8 would have provided sufficient erosion control at the hotspot instead of the construction of the groin spur and toe extension. **Figure IV-12** shows the structural configuration implemented in this model run and the predicted shoreline position after an 8-yr time period. For comparison, the 8-yr shoreline is also shown for Option 1 and the existing conditions model.

As shown, the predicted future shoreline position for Option 3 is significantly landward of the Option 1 shoreline position directly west of groin 8. While this simple fix may have reduced the erosional hotspot, it appears that this configuration may still yield potential erosion problems around the hotspot area, threatening structures directly west of groin 8. Therefore, Option 1 remains the most viable alternative involving demolition of existing structures only.

4. *Options 4a and 4b*

In Options 4a and 4b the toe extension and spur are removed and a new breakwater is placed offshore. This breakwater is placed slightly further offshore than the existing breakwaters to promote sediment transport movement towards the hotspot and to minimize potential tombolo formation that might block sediment transport. The proposed structure is placed approximately 175 feet from the end of breakwater 7 based on the average gap width across the existing breakwater field. The length of this breakwater is set to 220 feet based on the average length of the existing breakwaters. The construction of this breakwater would utilize rock from the demolition of the existing spur and toe extension.

In Option 4a, groins 8 and 9 are left at their existing lengths. In Option 4b, groin 8 is shortened by 50 feet from the existing length. **Figure IV-13** shows the structural configurations implemented for both Options 4a and 4b and the resulting predicted shoreline positions after an 8-yr time period. For comparison, the 8-yr shoreline is also shown for the existing conditions model.

While both options show relative improvements westward of the hotspot in comparison to existing conditions, Option 4a shows less relative loss on the updrift side of groin 8. As described for previous alternative comparisons (Options 1-2), additional shortening of groin 8 results in reduced sediment trapped on the updrift side and consequential shoreline retreat. Therefore, Option 4b was discarded as it presents a potential threat eastward of the historical hotspot area. However, Option 4a was considered to offer an improved transition through this area with minimal updrift impacts.

5. *Option 5*

Option 5 is a variation of Option 4a in which groin 9 is shortened by 150 feet. The objective of this model run was to test whether shortening of groin 9 would improve the overall transition along the shoreline bend and allow additional sediment transport to enter the hotspot area, without causing shoreline retreat on the updrift side. **Figure IV-14** shows the structural configuration implemented for Option 5 and the resulting predicted shoreline position after an 8-yr time period. For comparison, the 8-yr shoreline is also shown for Option 4a and the existing conditions model.

As shown, the predicted shoreline position for Option 5 is slightly seaward of that for Option 4a downdrift of groin 9 and moving across the hotspot area. However, updrift of groin 9, the shoreline position for Option 5 is slightly further landward than the shoreline position for Option 4a. This relative difference again presents a concern that shortening of groin 9 may result in negative impacts towards the east.

6. *Options 6 and 7*

Options 6 and 7 include the addition of one and two breakwaters, respectively, towards the east. The objective of these options was to investigate whether implementation of additional breakwaters around the shoreline bend would provide a more stabilized shoreline and would minimize impacts east of the hotspot. In Option 6, one additional breakwater was added eastward and aligned with the new breakwater proposed in Option 4a. Again, this breakwater was added using the average length of existing breakwaters (220 ft) and the average gap width between existing breakwaters (175 feet). In Option 7, two additional breakwaters were added eastward as done in Option 6 (assuming an average length and gap width). In both options, groin 9 was shortened by 150 feet to allow increased sediment transport to enter the areas being protected by additional breakwaters. **Figure IV-15** shows the structural configuration implemented for Options 6 and 7 and the resulting predicted shoreline positions for both alternatives after an 8-yr time period. For comparison, the 8-yr shoreline is also shown for Option 4a and the existing conditions model.

The addition of breakwaters towards the east results in accretion due to salient formation on the updrift side of groin 8. However, the salient formation on the downdrift side of groin 8 is reduced as less material is reaching this area. Relative to Option 4a, the shoreline positions on the downdrift side are significantly landward after an 8-yr time period. Therefore, the potential negative impacts downdrift of groin 8 do not outweigh the added benefit of the breakwaters on the updrift side of groin 8.

7. Option 8

Finally, the addition of short low-crested groins between the existing and proposed breakwaters was investigated. For this option, the structural configuration involved removal of the existing spur and toe extension to form a new offshore breakwater as implemented in Option 4a. The eastern groins were left at the existing lengths. However, additional short groins were added between breakwaters 6 and 7 and breakwater 7 and the new proposed breakwater. The expectation of this structural addition was that the short groins might further stabilize the shoreline in the embayments between breakwaters in the event that the proposed options do not fully recover the hotspot areas. **Figure IV-16** shows the structural configuration implemented for Option 8 and the resulting predicted shoreline position after an 8-yr time period. For comparison, the 8-yr time period is also shown for Option 4a and the existing conditions model.

The model results revealed that relative to Option 4a, there is no significant benefit to building the short low-crested groins in the hotspot areas west of groin 8. The shoreline positions are almost identical following an 8-yr time period. Furthermore, the resulting shoreline positions are just seaward of the groin tips, indicating that the erosion is not severe enough that the groins would be fully utilized.

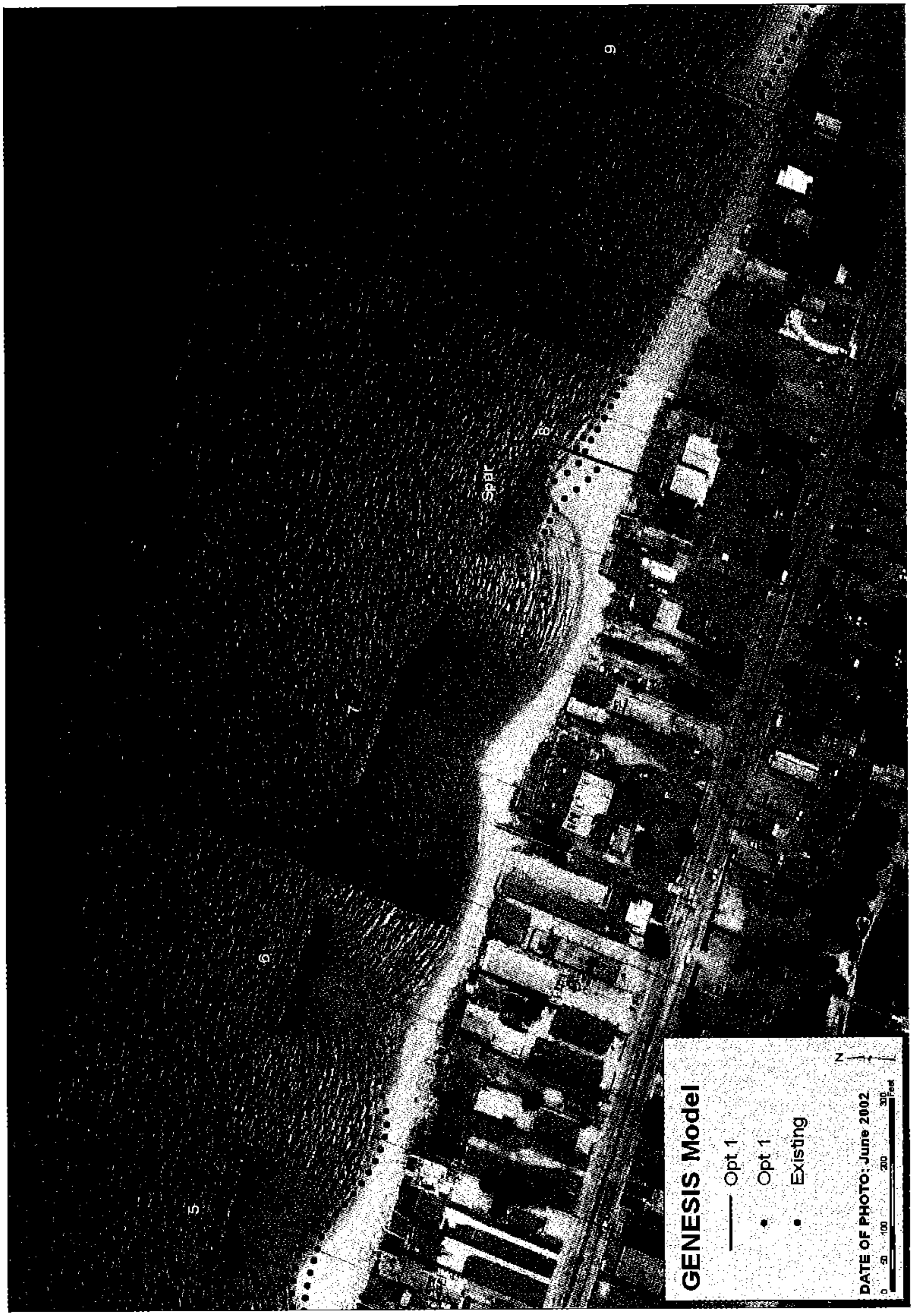


Figure IV-10 Option 1 GENESIS Model Results

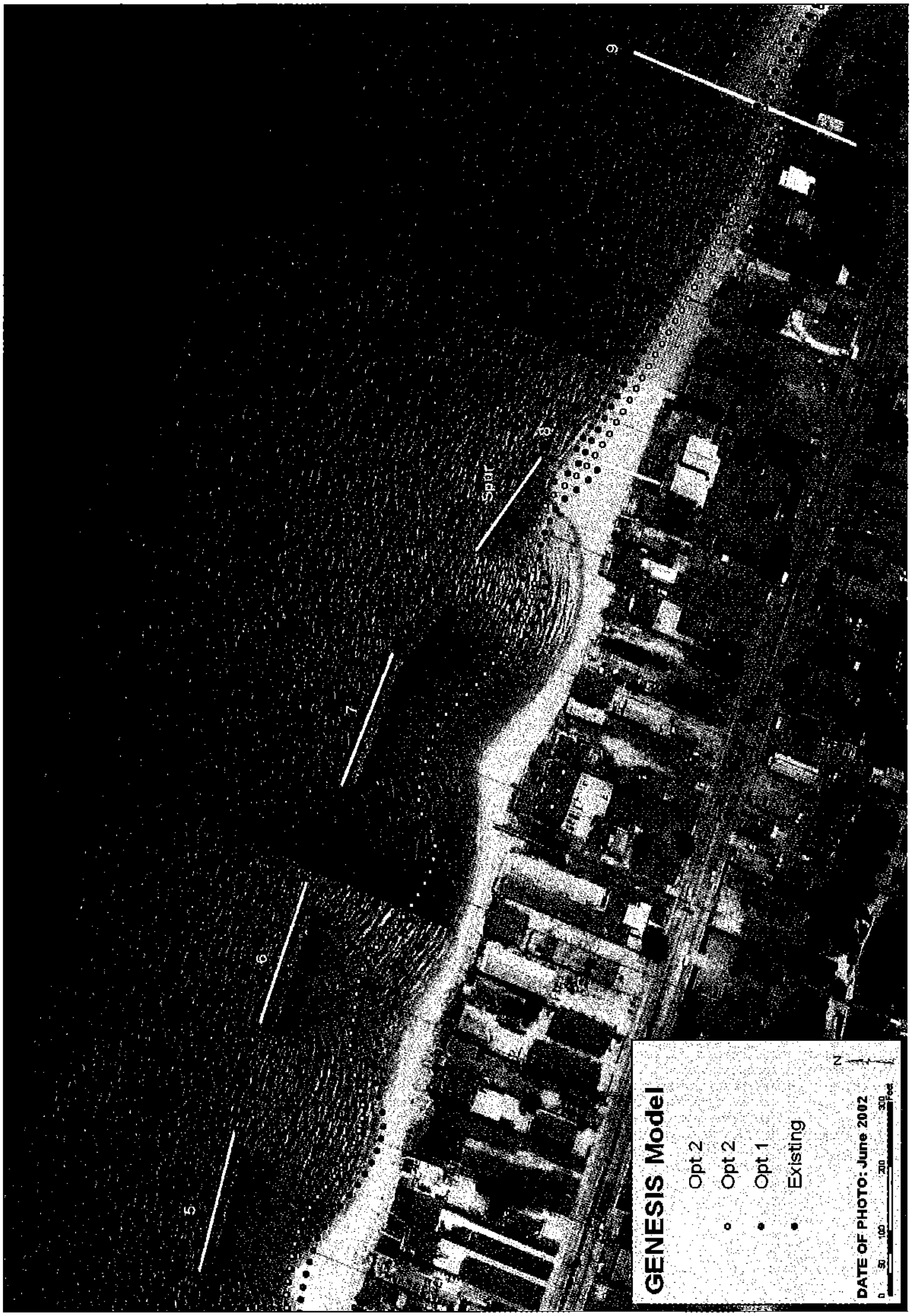


Figure IV-11 Option 2 GENESIS Model Results

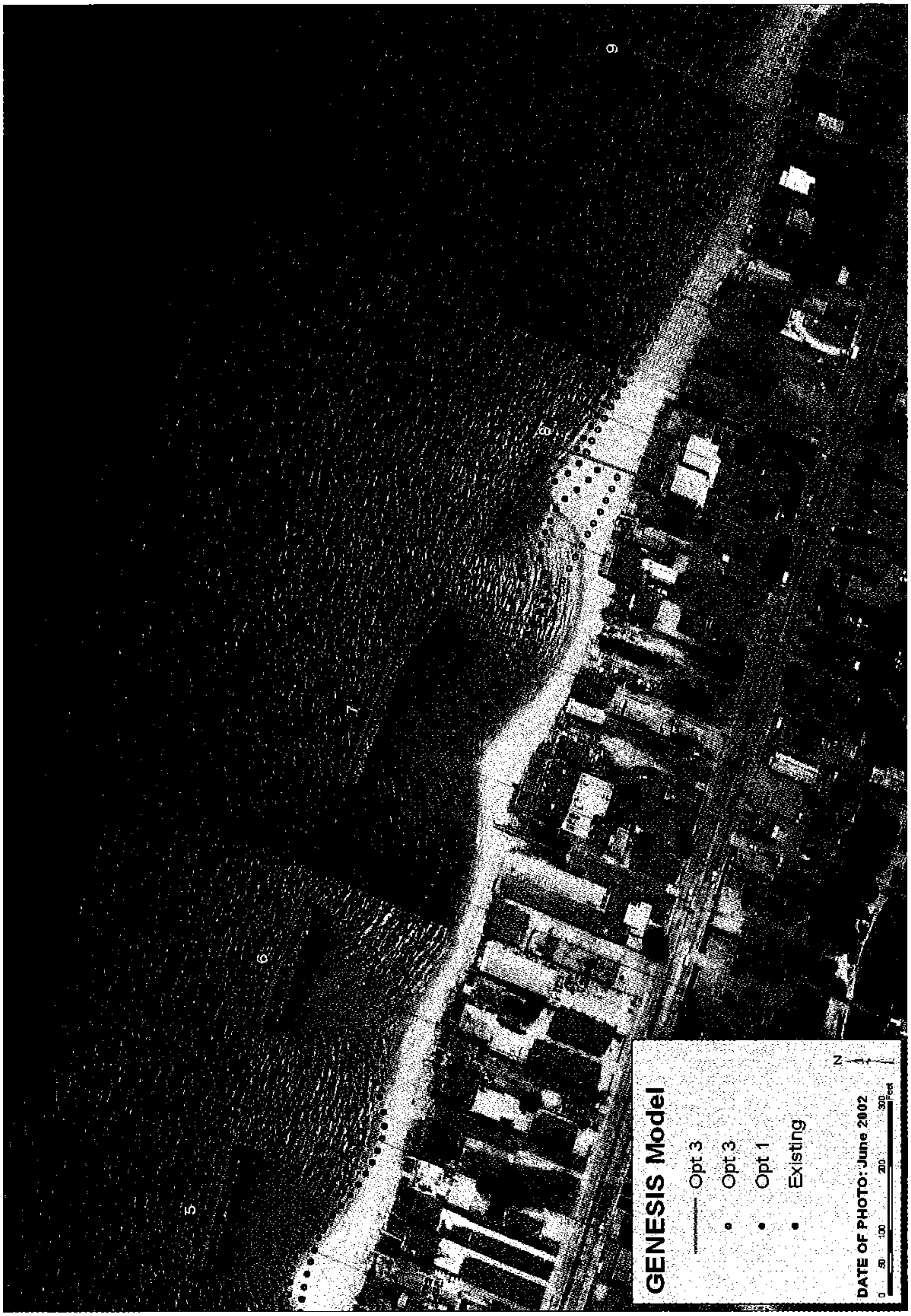


Figure IV-12 Option 3 GENESIS Model Results

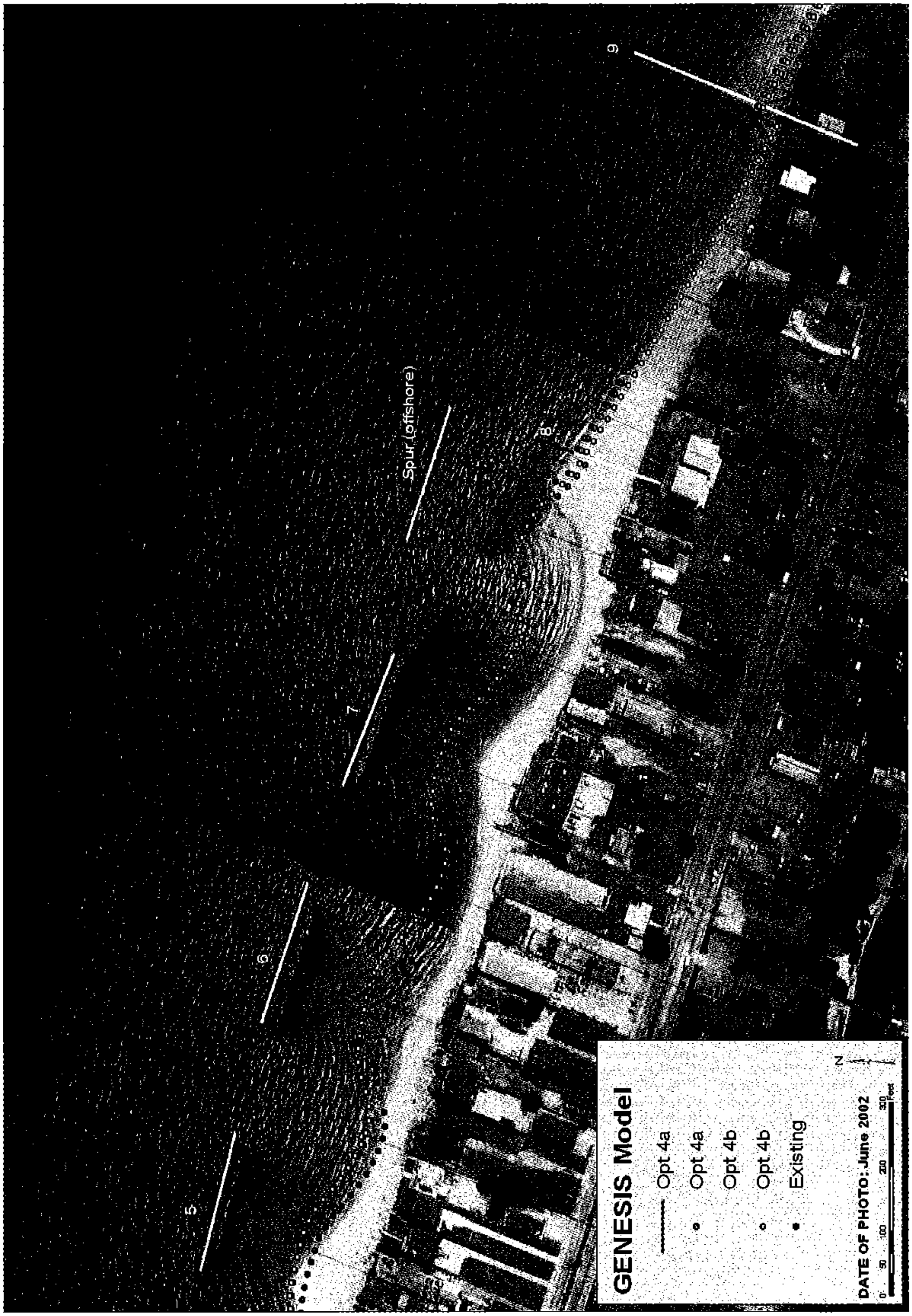


Figure IV-13 Options 4a and 4b GENESIS Model Results

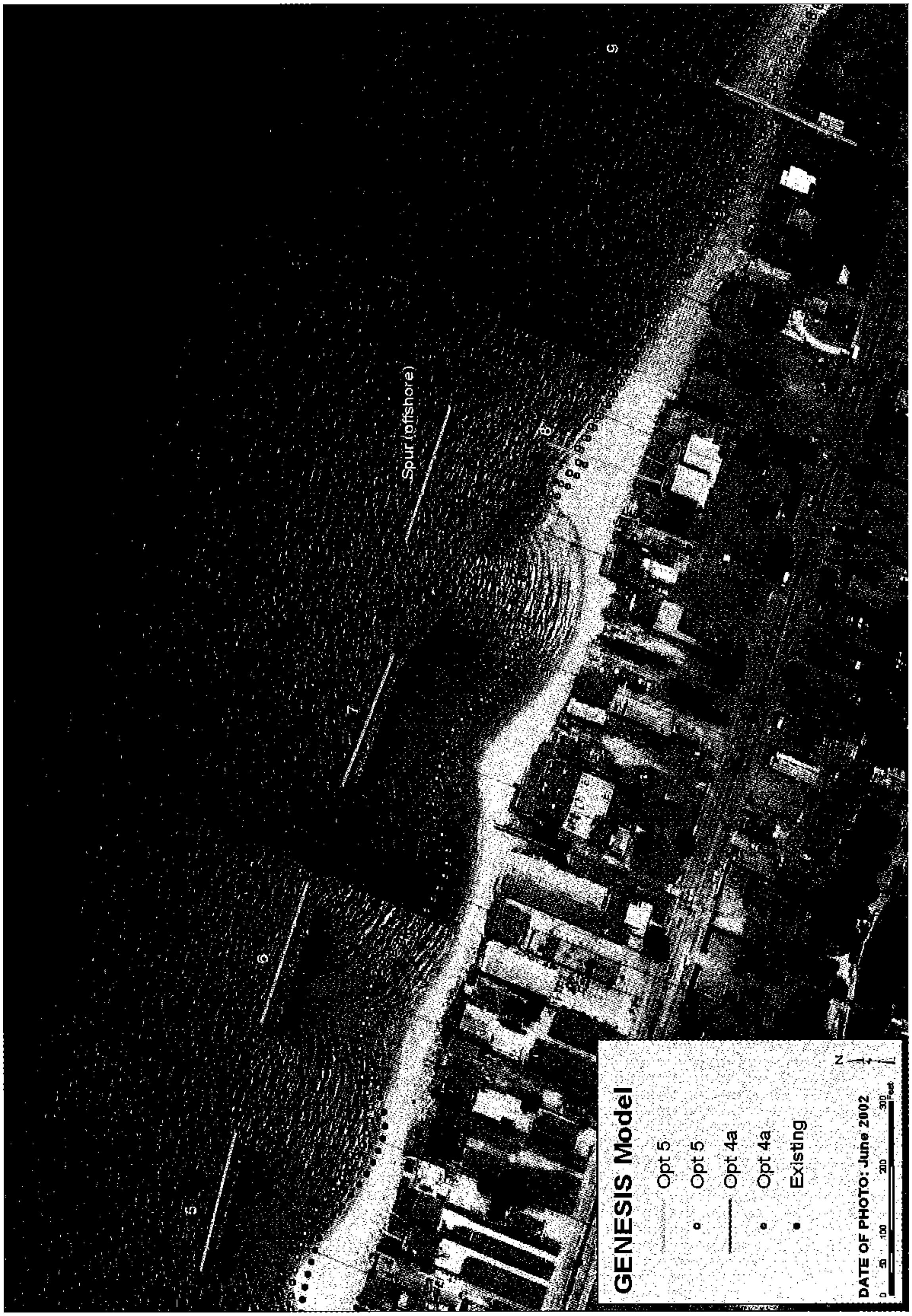


Figure IV-14 Option 5 GENESIS Model Results

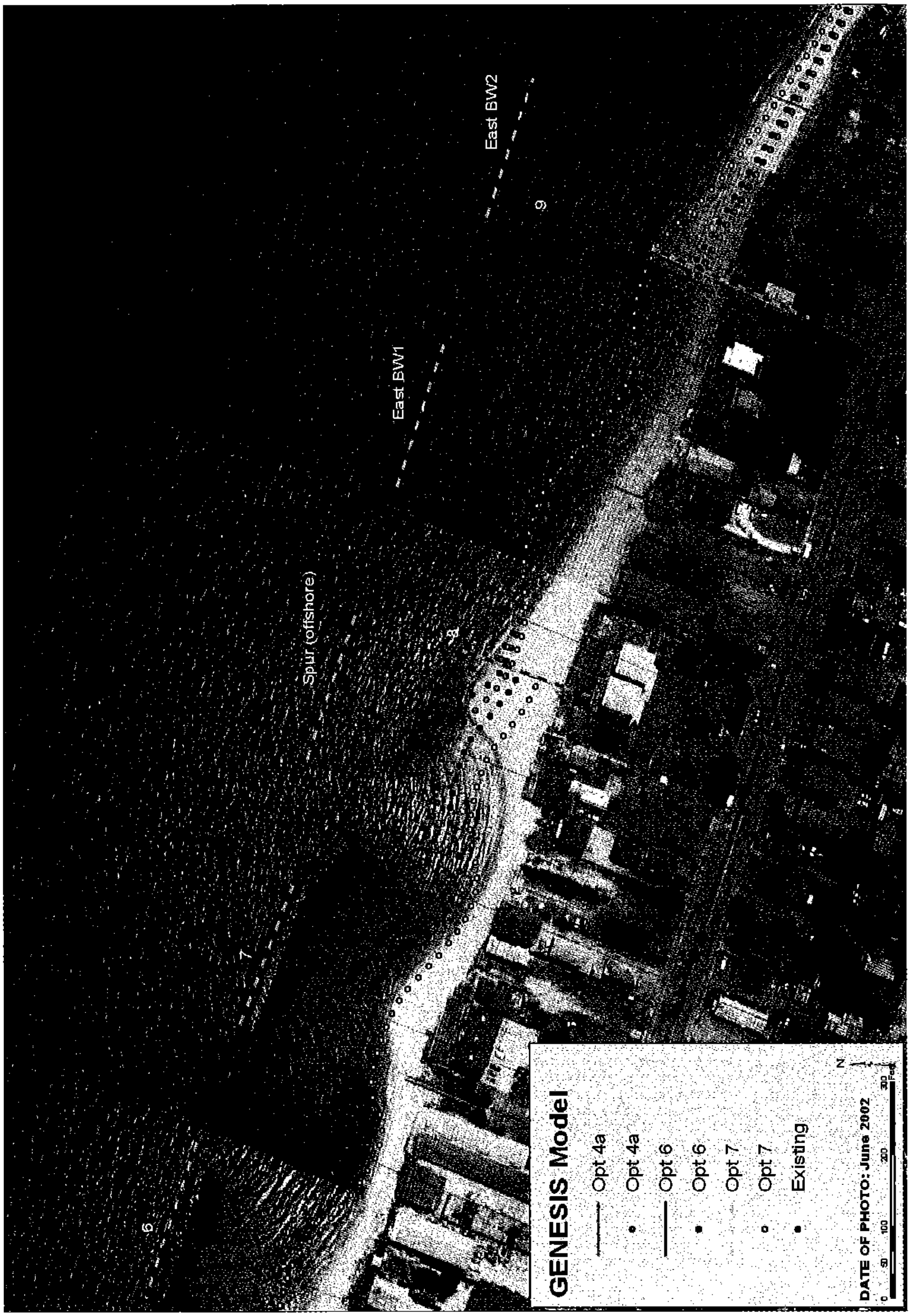


Figure IV-15 Option 6 and 7 GENESIS Model Results

Figure IV-16 Option 8 GENESIS Model Results

H. OPINION OF PROBABLE COSTS FOR MODELED ALTERNATIVES

An opinion of probable costs was developed for each of the proposed alternatives and is presented in **Table IV-3**. Detailed opinions of probable costs are presented in **Appendix A**. The unit costs used in the opinions of probable cost were provided by local contractors familiar with constructing these types of projects.

Table IV-3 Opinions of Probable Costs for Modeled Alternatives

OPTION	DESCRIPTION	PROBABLE COST
1	Remove toe extension	$230,000
2	Remove toe extension, shorten groin 8 by 100'	$340,000
3	Remove toe extension and groin spur	$380,000
4a	Remove toe extension and groin spur and construct new breakwater	$660,000
4b	Remove toe extension and groin spur and construct new breakwater; shorten groin 8 by 50'	$750,000
5	Remove toe extension and groin spur and construct new breakwater; shorten groin 9 by 150'	$790,000
6	Remove toe extension and groin spur and construct new breakwater; shorten groin 9 by 150'; add one additional breakwater to east	$1,320,000
7	Remove toe extension and groin spur and construct new breakwater; shorten groin 9 by 150'; add two additional breakwaters to east	$1,840,000
8	Remove toe extension and groin spur and construct new breakwater; add short, low-crested groins between existing and proposed breakwaters	$1,320,000

I. SELECTION OF PREFERRED ALTERNATIVES

Option 1 and Option 4a were selected as the preferred alternatives for further analysis in Delft3D, based on the GENESIS modeling results and comparison of probable costs. **Figure IV-17** shows the structural configuration implemented for both of these options and the resulting predicted shoreline positions after an 8-yr time period. For comparison, the 8-yr time period is also shown for the existing conditions model. The GENESIS modeling results revealed that, relative to existing conditions, both options are expected to improve the shoreline transition across the entire hotspot extent without worsening conditions updrift or downdrift. Based on the GENESIS results, Option 4a induces a salient formation behind the new proposed breakwater. With this salient formation, the overall transition of the shoreline appears smoother across the hotspot relative to the resulting shoreline for Option 1. Option 4a also has less impact to areas east of groin 8. Option 1 involves removal of the toe extension on breakwater 7 only. The opinion of probable cost for this option is $230,000. Option 4a involves removal of the toe extension and spur and the addition of a new breakwater offshore. The opinion of probable cost for Option 4a is $660,000. Option 1 and Option 4a were both modeled in Delft3D as will be discussed in the following **Section V**.

Figure IV-17 GENESIS Model Results for Preferred Alternatives

V. MODELING OF COASTAL PROCESSES WITH DELFT3D

This section describes the development of a suite of models and a simulation approach used to examine coastal processes (i.e., hydrodynamics, waves, sediment transport, and morphological changes) under existing, pre-construction (conditions prior to the construction of the spur and toe extension), and future with project conditions for the two selected design alternatives presented previously. The models were also used to assess and compare the relative performance of these proposed alternatives under wave and hydrodynamic conditions roughly equivalent to a 5-year period.

A. OVERVIEW OF THE DELFT3D MODELING SYSTEM

Modeling of coastal processes for this part of the study was performed using the Delft3D modeling system. Delft3D is an integrated surface water modeling system developed by WL | Delft Hydraulics in the Netherlands. The system is based on a flexible framework which simulates two- and three-dimensional flow, waves, water quality, ecology, sediment transport and bottom morphology and the interactions between those processes. The package gives direct access to state-of-the-art process knowledge, accumulated and developed at one of the world's oldest and most renowned hydraulic institutes. Delft3D consists of a number of well-tested and validated modules, which are linked to and integrated with one-another. Descriptions of the modules used in this study are provided in the following sections.

1. Hydrodynamics: Delft3D-FLOW

The hydrodynamic module Delft3D-FLOW simulates two-dimensional (2D, depth averaged) or three-dimensional (3D) unsteady flow and transport phenomena resulting from tidal and/or meteorological forcing, including the effect of density differences due to a non-uniform temperature and salinity distribution (density-driven flow). This model can be used to predict the flow in shallow seas, coastal areas, estuaries, lagoons, rivers and lakes. When the fluid is vertically homogeneous, a depth-averaged approach is appropriate. Delft3D-FLOW is able to run in two-dimensional mode (one computational layer), which corresponds to solving the depth-averaged equations.

Delft3D-FLOW's system of equations consists of the horizontal equations of motion, the continuity equation and the transport equations for conservative constituents. The equations are formulated in orthogonal curvilinear co-ordinates. The flow is forced by tide at the open boundaries, wind stress at the free surface, and pressure gradients due to free surface gradients (barotropic) or density gradients (baroclinic). Delft3D-FLOW solves the Navier Stokes equations for an incompressible fluid, under the shallow water and the Boussinesq assumptions.

2. Waves: SWAN Wave Model

The SWAN wave model, developed at Delft University of Technology in Netherlands, is based on the discrete spectral action balance equation and is fully spectral (in all directions and frequencies). The latter implies that short-crested random wave fields propagating simultaneously from widely different directions can be accommodated (e.g. a wind sea with super-imposed swell). SWAN computes the evolution of random, short-crested waves in coastal regions with deep, intermediate and shallow water and ambient currents. The SWAN model accounts for (refractive) propagation due to current and depth and represents the processes of wave generation by wind, dissipation due to whitecapping, bottom friction and depth-induced wave breaking and non-linear wave-wave interactions explicitly with state-of-the-art formulations. The SWAN model has successfully been validated and verified in several laboratory and complex field cases (Ris et al., 1999).

The SWAN model also has a dynamic interaction with the flow module of Delft3D (i.e. two way wave-current interaction). By this the effect of waves on current (via forcing, enhanced turbulence and enhanced bed shear stress) and the effect of flow on waves (via set-up, current refraction and enhanced bottom friction) are accounted for if the SWAN model is applied within Delft3D.

3. Sediment Transport and Morphology: Delft3D FLOW

Three-dimensional transport of suspended sediment is calculated in Delft3D by solving the three-dimensional advection-diffusion (mass-balance) equation for the suspended sediment. The local flow velocities and eddy diffusivities are based on the results of the hydrodynamic computations.

The elevation of the bed is dynamically updated at each computational time-step. This is one of the distinct advantages over an offline morphological computation as it means that the hydrodynamic flow calculations are always carried out using the correct bathymetry. At each time-step, the change in the mass of bottom sediment that has occurred as a result of the sediment sink and source terms is calculated. This change in mass is then translated into a change in thickness of the bottom sediment layer using the density of the bed material. This change in thickness is equivalent to a change in bed elevation, which is applied to the depth values stored at computational points.

The hydrodynamic model implementation used in the sediment transport and morphology model includes the effects of the waves on both nearshore hydrodynamics (i.e., longshore currents and wave setup) and sediment transport (i.e., increased bottom shear stresses and turbulence). It should be noted, however, that the model does not include all of the physics affecting beach profile changes during storm conditions, such as the three-dimensional wave and hydrodynamic processes that generate undertow and offshore sand transport. Nonetheless, this model will provide additional insight into erosion and accretion patterns in the 800 Block project area.

B. MODELING SCOPE AND APPROACH

In addition to the larger scale GENESIS modeling for the project, the Delft3D modeling system was used in order to provide insight into sediment transport patterns and morphological changes in the immediate vicinity of the 800 Block hotspot.

Two hydrodynamic computational models were developed for the 800 Block modeling study, namely: a large *regional* model of Chesapeake Bay and a *local* model. **Figure V-1** shows the relative location of both models. The regional model was used to provide hydrodynamic boundary conditions to the local model which was used to simulate hydrodynamics as well as sediment transport and morphological processes at a higher resolution.

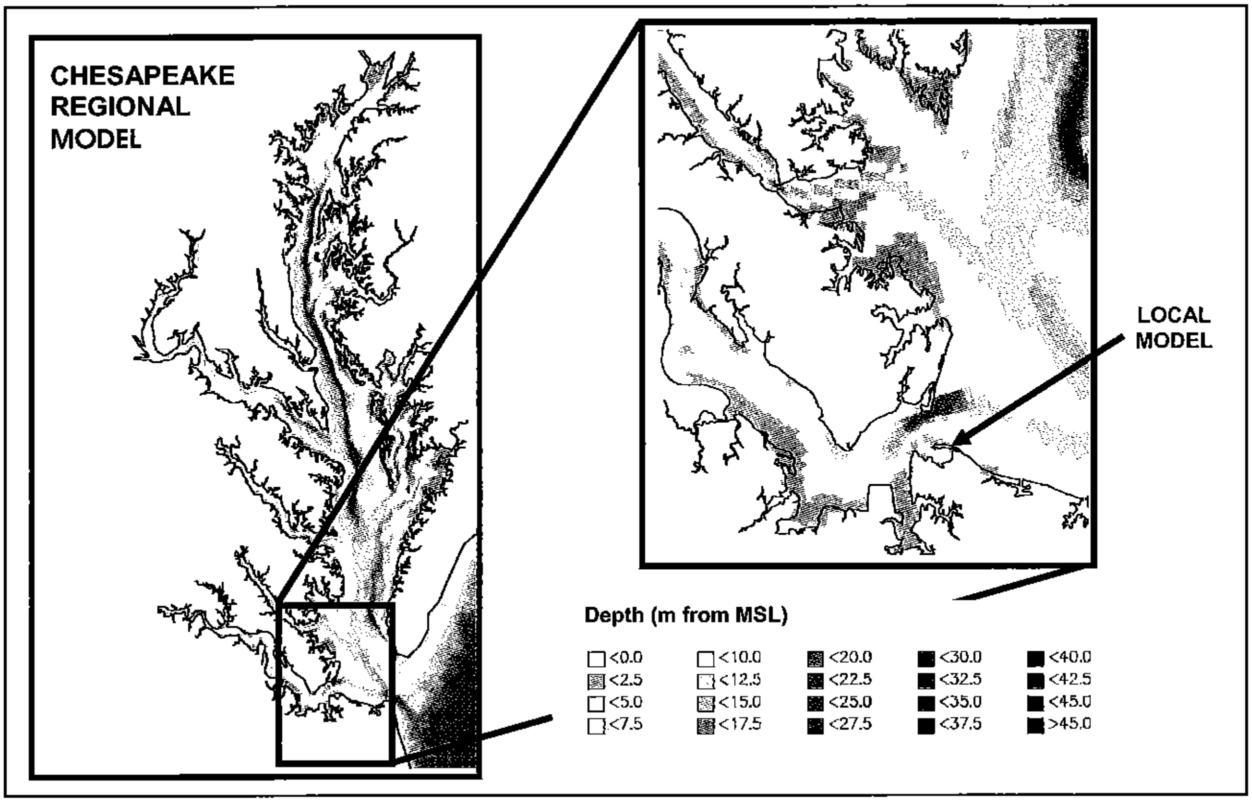


Figure V-1 Relative Locations of Delft3D Regional and Local Models

It should be noted that while the Delft3D model cannot specifically simulate a long-term time series of waves and water levels, it can be used to assess and compare the relative performance of various alternatives under representative wave/surge conditions. The Delft3D modeling system is a good complement to a long-term one-dimensional shoreline simulation model.

C. REGIONAL HYDRODYNAMICS

1. Model Grid

The Moffatt & Nichol 3D Hydrodynamic model of the Chesapeake Bay was used as the regional model. This model was used in 2D mode to create time series of boundary conditions for the local morphological model of 800 Block. The Chesapeake Bay model extends in the north from the entrance of the C&D canal on the Elk River approximately 200 miles south to the Chesapeake Bay bridge tunnel and then approximately further 100 miles offshore into the Atlantic Ocean. The model grid and extent are presented in **Figure V-2**. The model is built on a curvilinear computational grid. Over 23,000 computational grid points define the entire model. The grid resolution is variable throughout the model domain. The highest resolution is found at the offshore boundary throat: 11 km grid spacing along the axis of the shoreline and 3.5 km spacing cross shore.

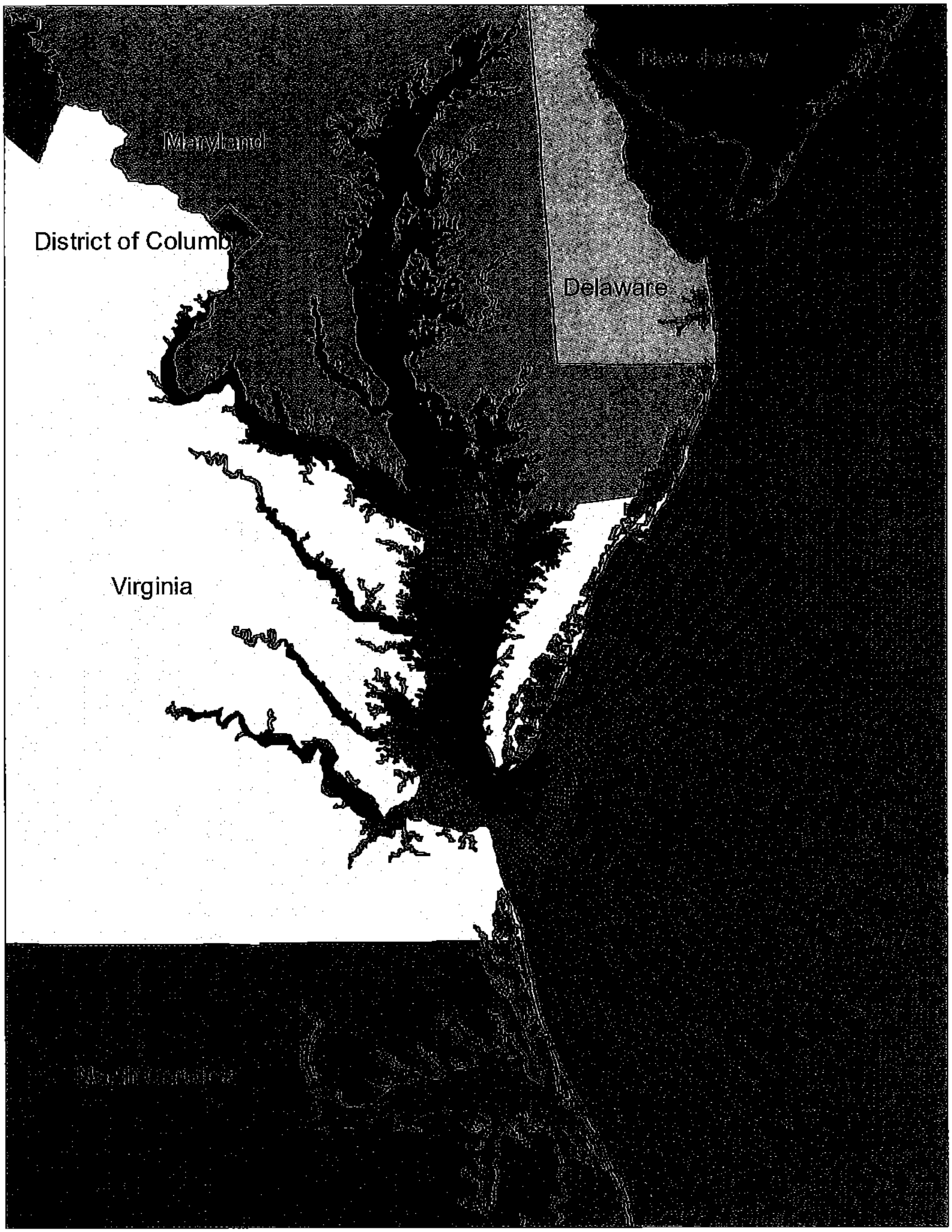


Figure V-2 Delft3D Regional Model Grid and Extent

2. Model Bathymetry

Regional model bathymetry was developed using NOAA data, particularly the NOS estuarine bathymetry for the bay area and the National Geophysical Data Center's GEODAS data sets. These data sources are integrated within the Delft3D modeling system by interpolating the values into the model grid using triangular interpolation. In areas of overlap, the most recent data was used. **Figure V-3** presents the regional model bathymetry derived from the above sources.

3. Boundary Conditions

Open boundaries to the model were defined at two locations – at the southern offshore boundary and at the northern most location at the junction of the Elk River with the C&D canal. The offshore boundary is defined as time series of water surface elevations. These time series were constructed from nine major tidal constituents extracted from the *Eastcoast 2001* database of tidal elevation and velocity constituents (Mukai et al, 1995). This database was developed to allow surface-water elevation and currents to be quickly and easily defined in open waters within the Western North Atlantic Tidal (WNAT) domain. The WNAT domain encompasses the Western North Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea. The hydrodynamic numerical model used in all the WNAT tidal database computations is ADCIRC-2DDI, the depth-integrated option of the two- and three-dimensional fully nonlinear hydrodynamic code ADCIRC (Luettich et al., 1992). The tidal variability along the boundary has also been considered. The northern most boundary location of the model is where the C&D canal joins the Elk River at Welch point. Current velocity time series based on NOAA constituents were applied at the boundary. In addition, the major contributions of fresh water into the system are also included. These contributions include the Susquehanna River, Potomac River, and James River.

4. Calibration

a) <u>Water Levels and Currents</u>

Simulated and observed water levels and currents were compared at various locations within the bay. Locations were selected so as to assess the model performance to the maximum possible spatial extent. All the calibration data were obtained from NOAA/NOS predictions. **Figure V-4** and **Figure V-5** show the water level and current calibration locations, respectively. **Figure V-6** and **Figure V-7** depict typical results for the water level and current calibration. Note that the regional model performs well for both water level and current predictions.

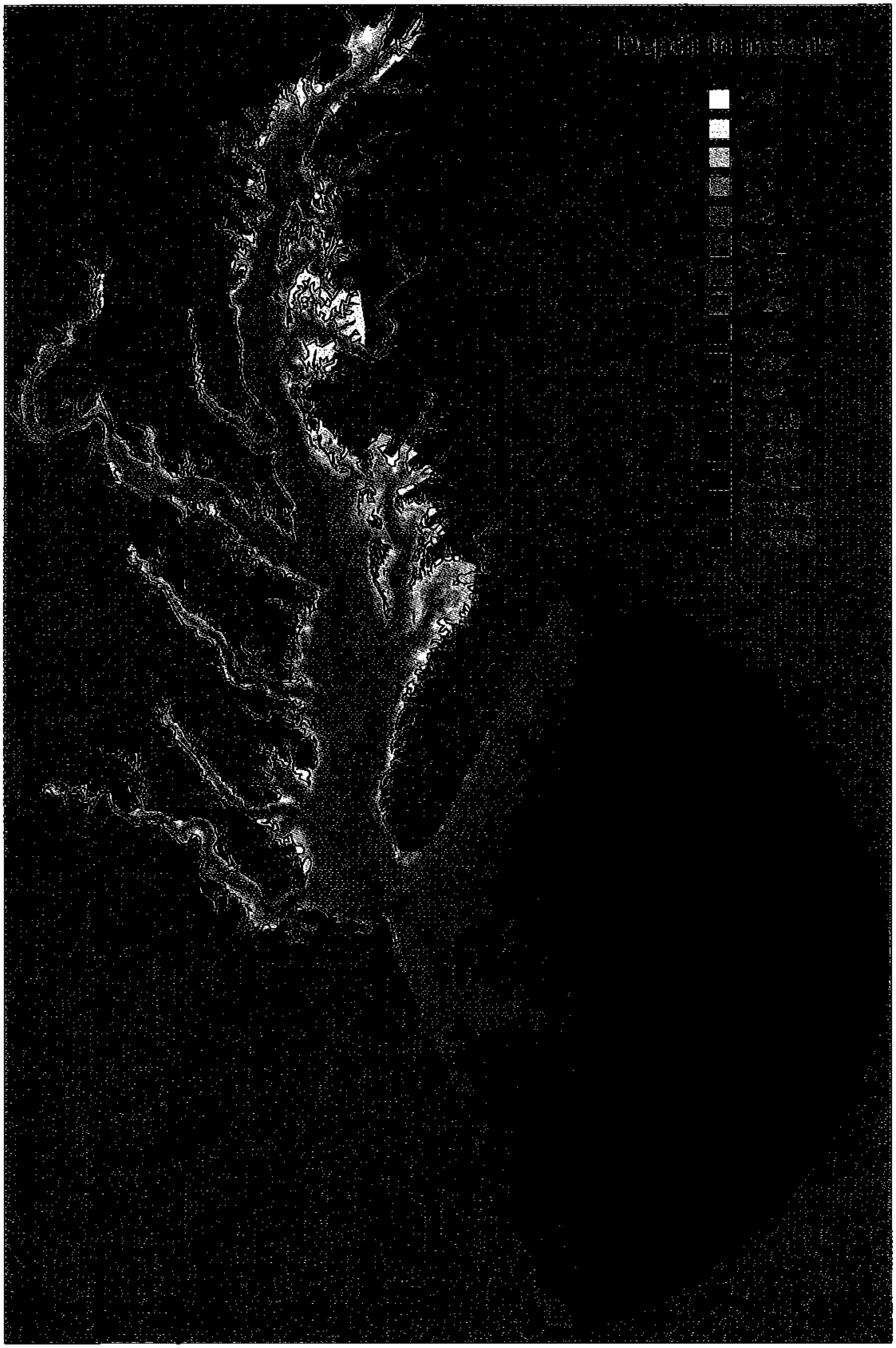


Figure V-3 Delft3D Regional Model Bathymetry

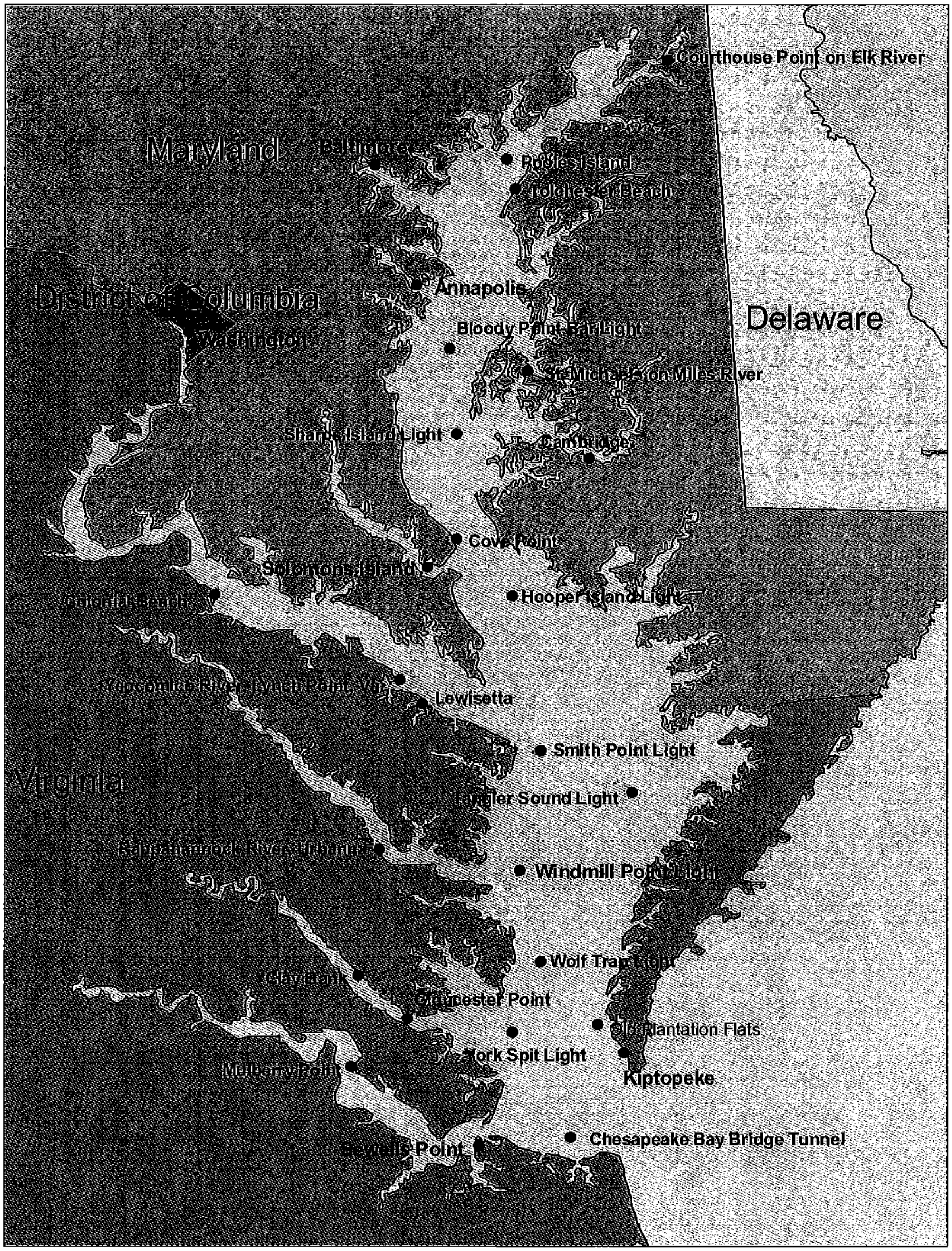


Figure V-4 Locations of Delft3D Regional Model Water Level Calibration

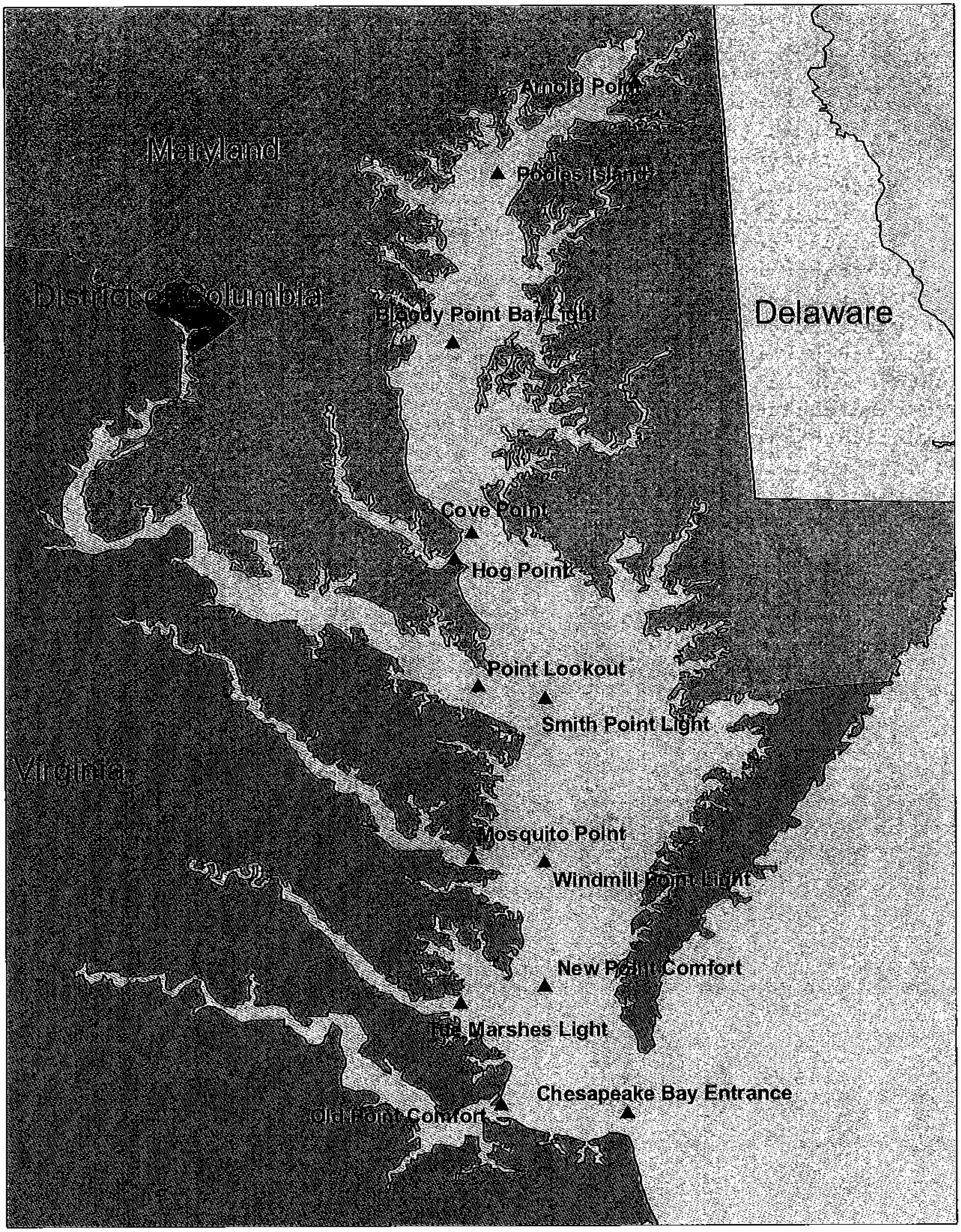
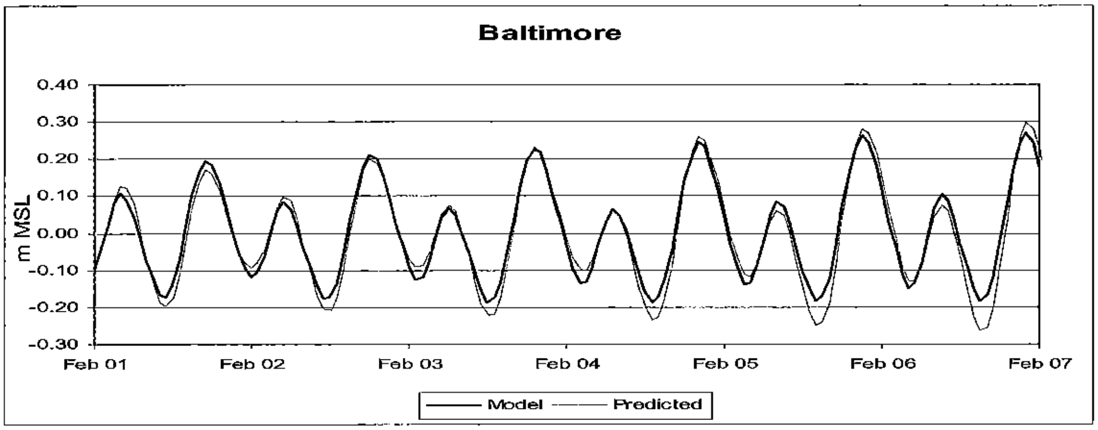
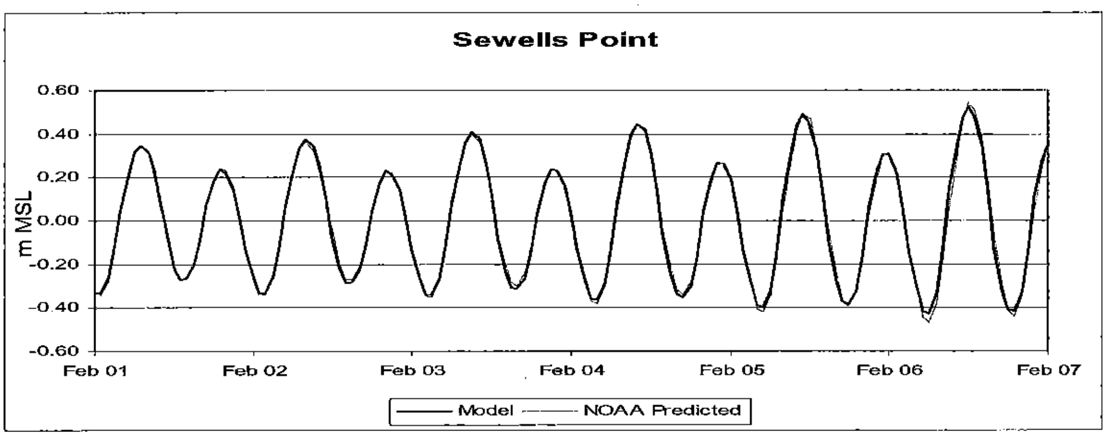


Figure V-5 Locations of Delft3D Regional Model Current Calibration





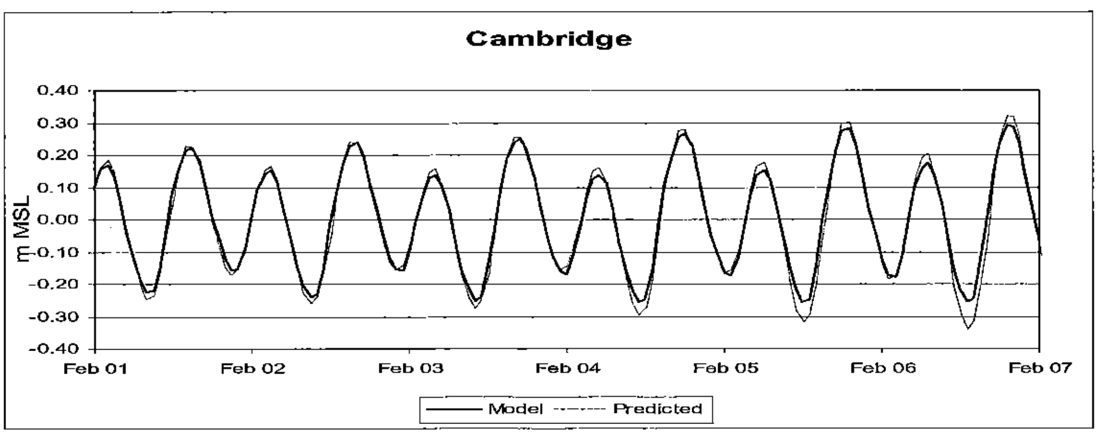
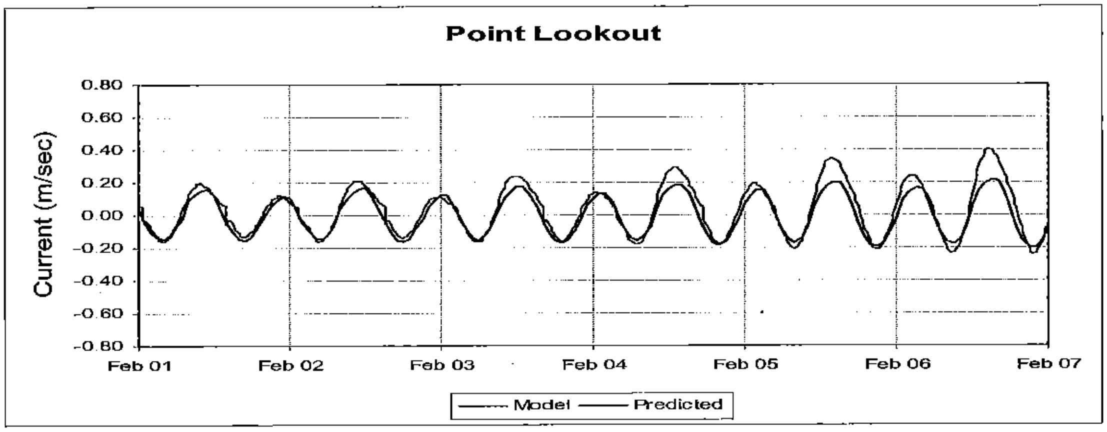
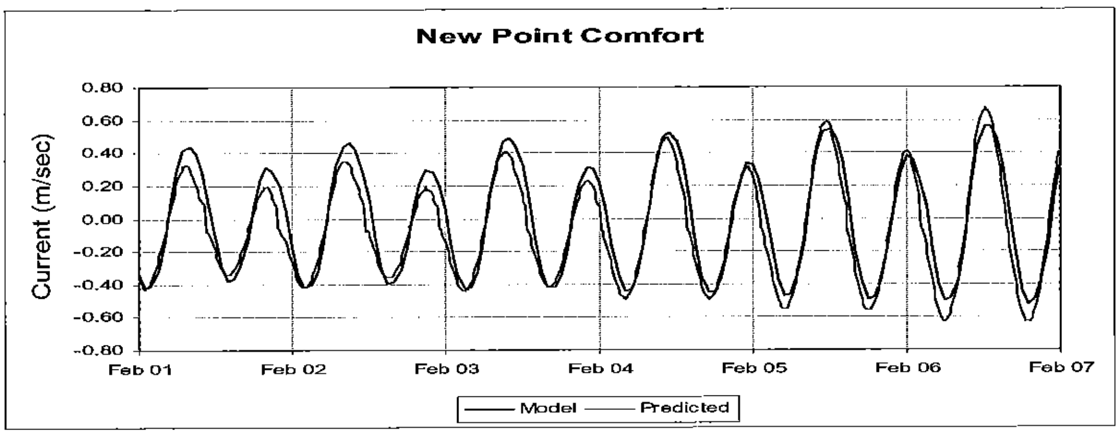


Figure V-6 Typical Results for Delft3D Regional Model Water Level Calibration





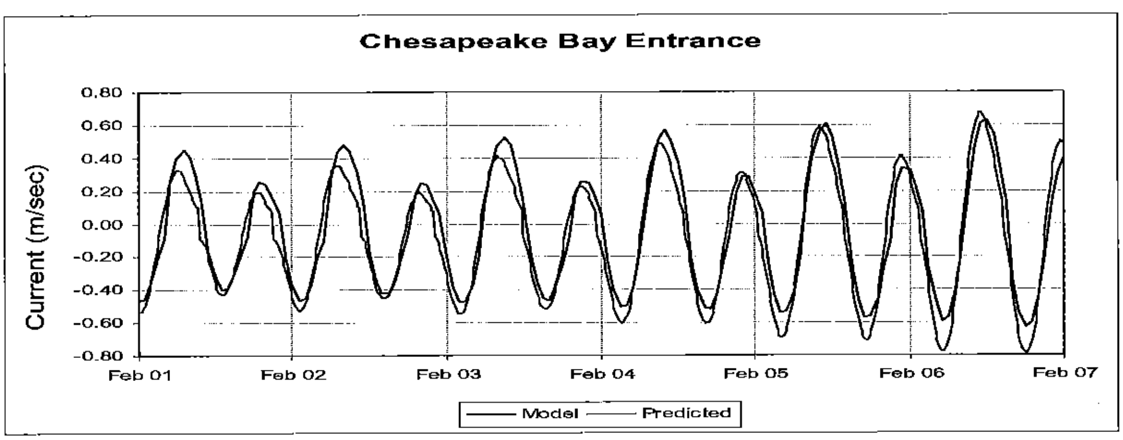


Figure V-7 Typical Results for Delft3D Regional Model Current Calibration

D. LOCAL MORPHOLOGICAL MODEL

1. Local Model Grid

Modeling of nearshore hydrodynamics, waves, sediment transport and morphology requires a grid with a relatively fine resolution. The regional grid used for modeling of regional hydrodynamics and waves is not well-suited for this task because increasing resolution in such a large grid would require extremely long simulation times. Therefore, a local high-resolution grid was developed to resolve these nearshore coastal processes in the vicinity of 800 Block.

Figure V-8 and **Figure V-9** present the local grid and bathymetry, respectively. The grid extends approximately 4600 feet from east to west; 1650 feet north to south. The offshore boundary is located in a water depth of 17 feet. The grid sizes range from 9 feet at the breakwater field to 65 feet near the offshore open boundary. A total of over 29,000 computational points comprise the local grid. The regional grid was used to drive the local grid during model simulations.

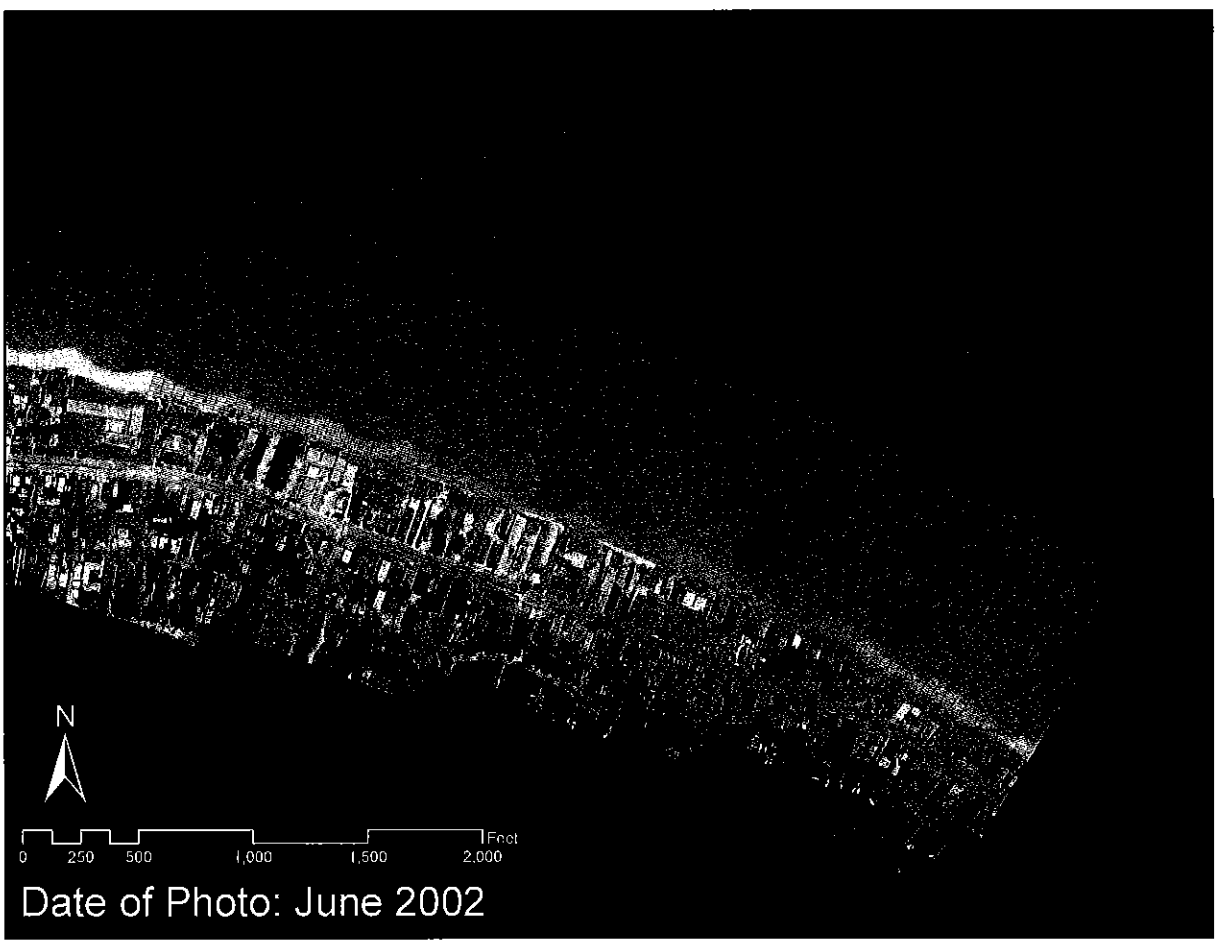


Figure V-8 Delft3D Local Model Grid and Extent

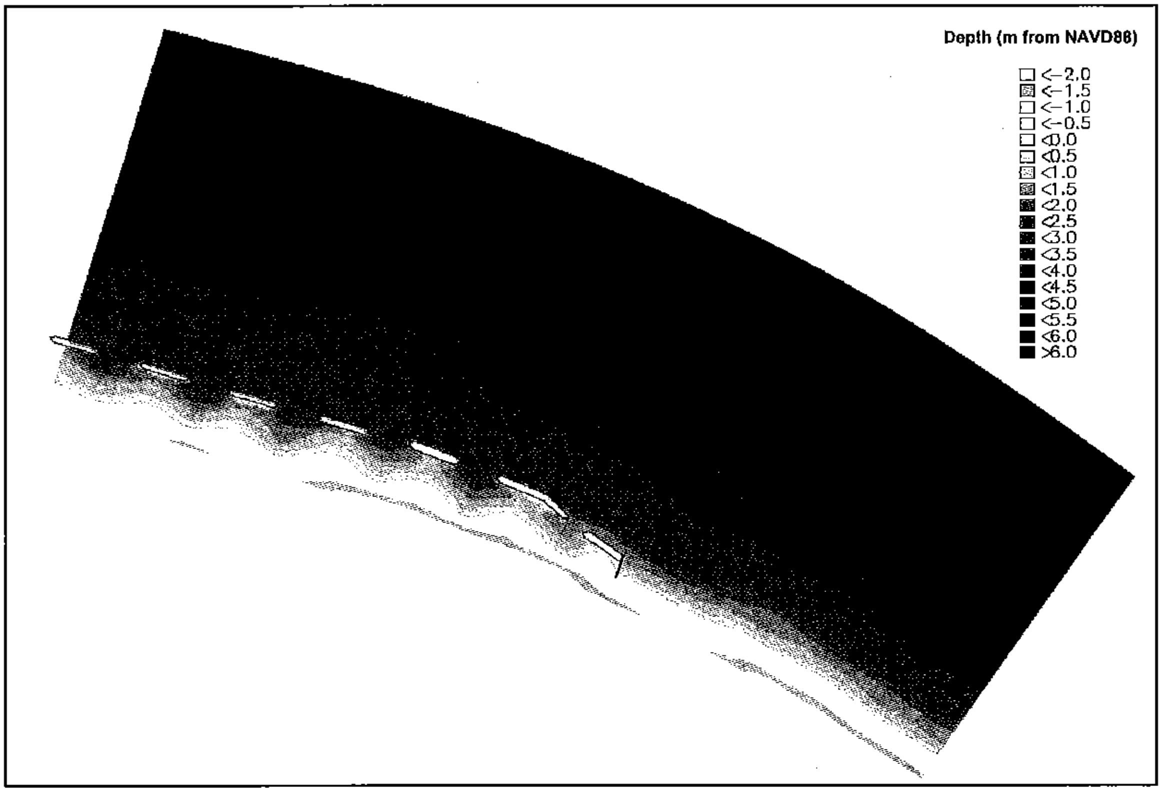


Figure V-9 Delft3D Local Model Bathymetry

For this application of the Delft3D sediment transport and morphology model, a constant grain size representing the average for the study area was applied throughout the domain: D_{50}=0.4 mm. This value is based on the median grain size of samples taken in the 800 Block project site in April, 2004. Sand was modeled with a specific density of 2650 kg/m^3 and a dry bed density of 1600 kg/m^3. Boundary conditions are only required at the open boundaries. Separate boundary conditions are required for suspended and bed load transport. For the suspended sediment transport, the boundary condition during inflow is defined as a concentration equal to equilibrium concentration, and during outflow it is equal to upstream concentration. For the bed load transport, a bed level condition is imposed where the bed level remains constant at the boundary segment.

2. Local Model Scenarios

The local Delft3D model was run for four unique structural configurations in order to test the efficacy of the selected design alternatives.

- Pre-construction: This scenario reflects the structural configuration prior to construction of the groin spur (representative of December, 1999).
- Existing Conditions: This scenario is based on the existing structural configuration.
- Option 1: This scenario involves the removal of the toe extension on breakwater 7.
- Option 4a: This scenario involves the removal of the toe extension on breakwater 7 and spur and the construction of a new breakwater offshore.

The local model bathymetry used for each model run was developed from the February-April, 2004 DTM which was built using measured survey data. The breakwater structures were defined in the model according to their geometry. The groin structures were implemented as thin dams in the Delft3D-FLOW module. Thin dams are infinitely thin objects which prohibit flow exchange between two adjacent computational cells without reducing the total wet surface and the volume of the model. In the wave model SWAN, the groin structures were implemented as obstacle segments. Such obstacle segments affect the wave field in two ways: first, they reduce the wave height locally along their length, and second, they cause diffraction around their ends. The purpose of thin dams and obstacle segments is to represent small obstacles that influence the nearfield effects of flow and waves.

E. LOCAL WAVE MODEL

The Delft3D morphological model integrates the effects of waves, currents and sediment transport on morphological developments. The different processes (hydrodynamics, waves, sediment transport and morphology) are coupled via a bottom evolution model based on sediment conservation, and therefore, the flow fields are always calculated using the latest updated bathymetry. Hence, a local wave model must be developed so that the effects of the waves may be incorporated in the morphological model. A rectangular grid was utilized for the SWAN model, with bathymetry based on the available bathymetry sources described previously. The rectangular grid extends approximately 10,000 feet from east to west; 2,000 feet north to south. The grid sizes are 60 feet everywhere. A total of over 5,800 computational points comprise the rectangular grid used for the SWAN model.

F. REPRESENTATIVE INPUT WAVE AND SURGE DATA

Because detailed modeling over large space and time scales requires excessively long simulation times, wave and water level data must be schematized. This approach reduces computational intensity by selecting a limited number of representative hydrodynamic conditions to use as input to the morphological model. It should be noted that while the Delft3D model cannot specifically simulate a long-term time series of waves and water levels, it can be used to assess and compare the relative performance of various alternatives under representative hydrodynamic conditions. The Delft3D modeling system is a good complement to a long-term one-dimensional shoreline simulation model.

Two representative wave environments were tested with the Delft3D morphological model, namely, typical sea and swell wave conditions. Similar to GENESIS, measured spectral wave data from the USACE Field Research Facility (FRF) in Duck, NC was selected for use in the Delft3D model. The measured spectral wave data was divided into sea and swell components and transformed uniquely to the study area, yielding a 13-year time series spanning from 1991 to 2004. The wave data and associated methodologies used to develop the nearshore refraction data is discussed in detail in the East Ocean View report (M&N, June 2004) and in previous sections of this report. Statistical analysis of the transformed sea and swell wave conditions was performed in order to determine the predominant representative wave conditions to be applied within the Delft3D model. Based on the results from the model runs, it can be concluded that the morphological changes in this area primarily result from the action of storm waves. Minimal changes in bathymetry were observed for model runs with swell wave conditions. In summary, the following representative sea wave conditions corresponding to the 1-year return period were used: significant wave height (H_s) of 5.6 ft, peak period (T_p) of 5 sec, direction (θ) of 40 degrees from North.

Water level data were obtained from the results of the regional hydrodynamic model and applied at the local model open boundaries. An additional surge value of 2.25 feet corresponding to a 1-year return period was added to the water level data. The surge was computed based on a statistical analysis of water level data from the NOAA/NOS Sewells Point gage for the period of January 1994 through October 2004 and predicted astronomical tides. The 1-year return period conditions were applied continuously in the model for approximately 30 days, which is equivalent to roughly 5 years of storm impacts. It is important to note that this model does not account for natural recovery processes that would take place between storm events. Furthermore, the Delft3D model runs only considered one set of wave conditions while the GENESIS modeling considered wave conditions expressed at the site over a 13-yr time period. Therefore, the Delft3D model results do show expected behavior during strong nor'easters but not long-term shoreline response as GENESIS does.

G. PRE-CONSTRUCTIONS AND EXISTING CONDITIONS MODELS

1. Pre-Construction Results

The objective of this analysis was to verify that the Delft3D model reproduced the erosional hotspot downdrift of groin 8 that originally warranted the construction of the groin spur and successive erosion control projects.

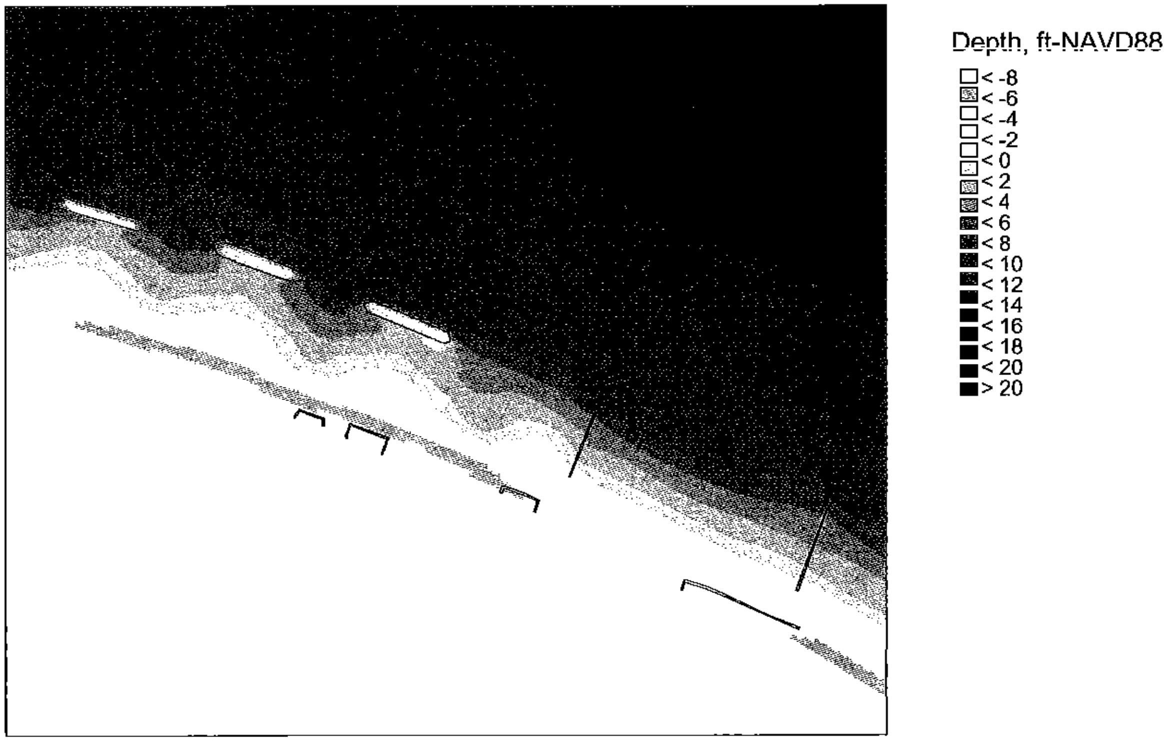
Figure V-10 shows the initial and final bathymetries for the pre-construction simulation. **Figure V-11** shows the accumulated changes during the pre-construction simulation. The results show increased erosion over time west of groin 8 with the application of sea waves at the site of the future spur. Therefore, it can be concluded that the Delft3D model reproduced the development of the erosional hotspot which warranted the previous erosion control projects.

2. Existing Conditions Results

An existing conditions model was run to determine the impacts on the study area with no mitigation of the existing erosion problem. Similar to the pre-construction run, the existing conditions model run involved a storm simulation representing the predicted future response of the project site under the action of waves and surge roughly equivalent to a 5-yr period.

Figure V-12 shows the initial and final bathymetries for the existing conditions simulation. **Figure V-13** shows the accumulated changes during the existing conditions simulation. Based on the model results, it can be concluded that the erosion control structures (spur and toe extension of breakwater 7) have reduced the rate of erosion at the historical hotspot. However, the accretion behind breakwater 7 raises concerns for potential tombolo formation and blocking of sediment transport from the east. This shoreline response is also consistent with recent site observations and GENESIS simulation results.

Initial Bathymetry



Final Bathymetry

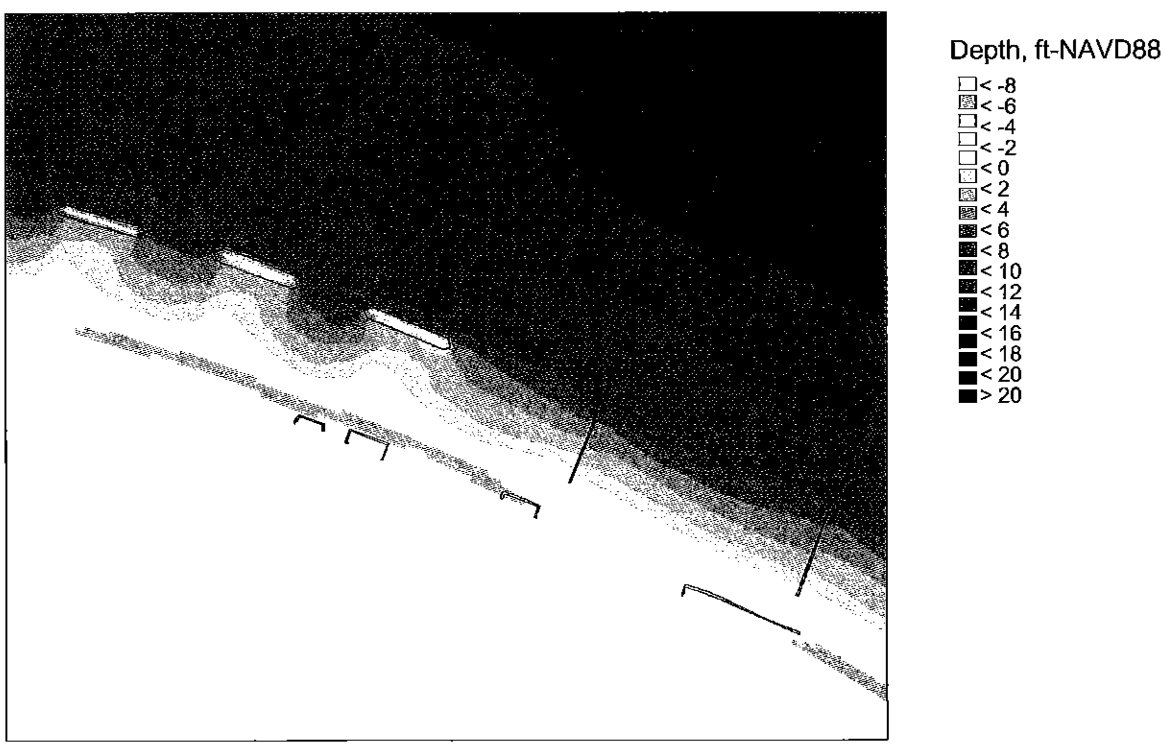


Figure V-10 Delft 3D Initial and Final Bathymetries for Pre-Construction Scenario

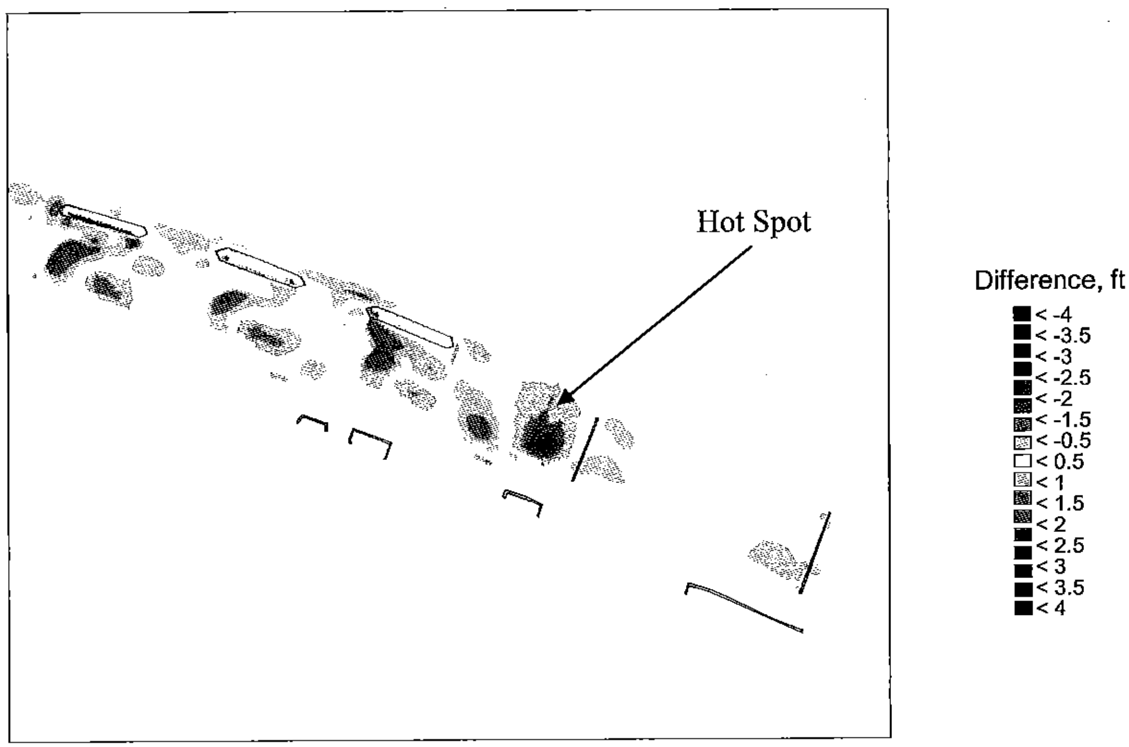
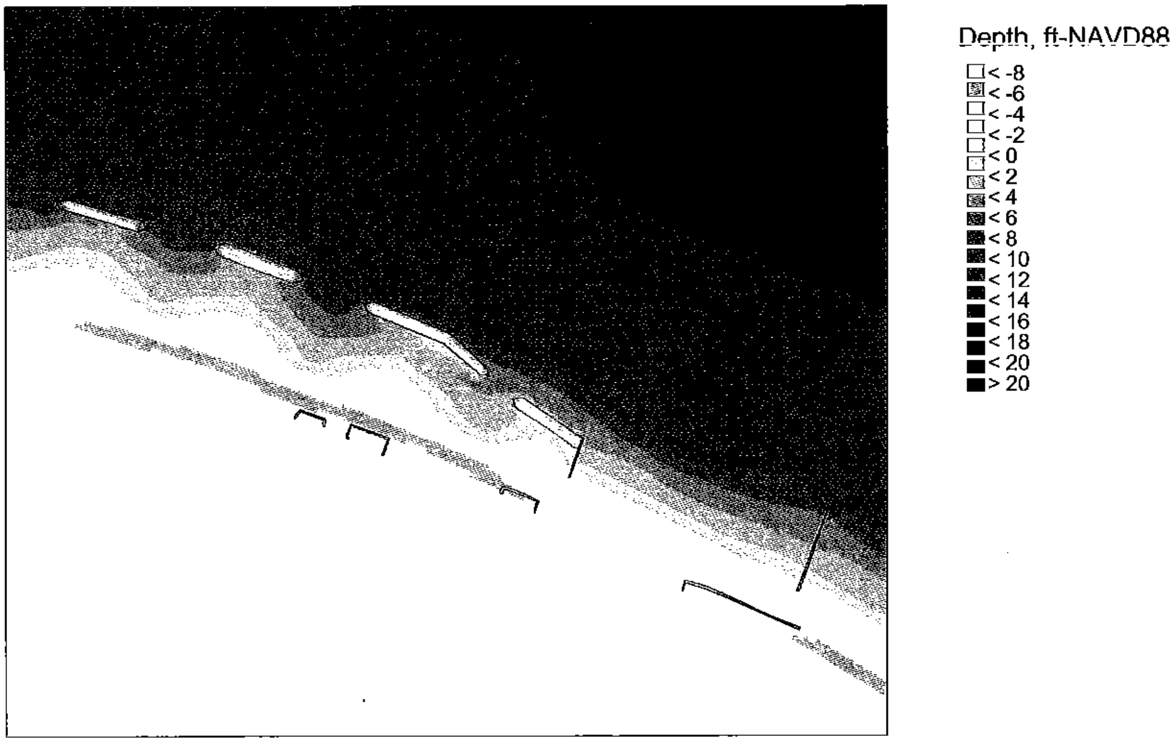


Figure V-11 Delft 3D Accumulated Changes for Pre-Construction Scenario

Initial Bathymetry



Final Bathymetry

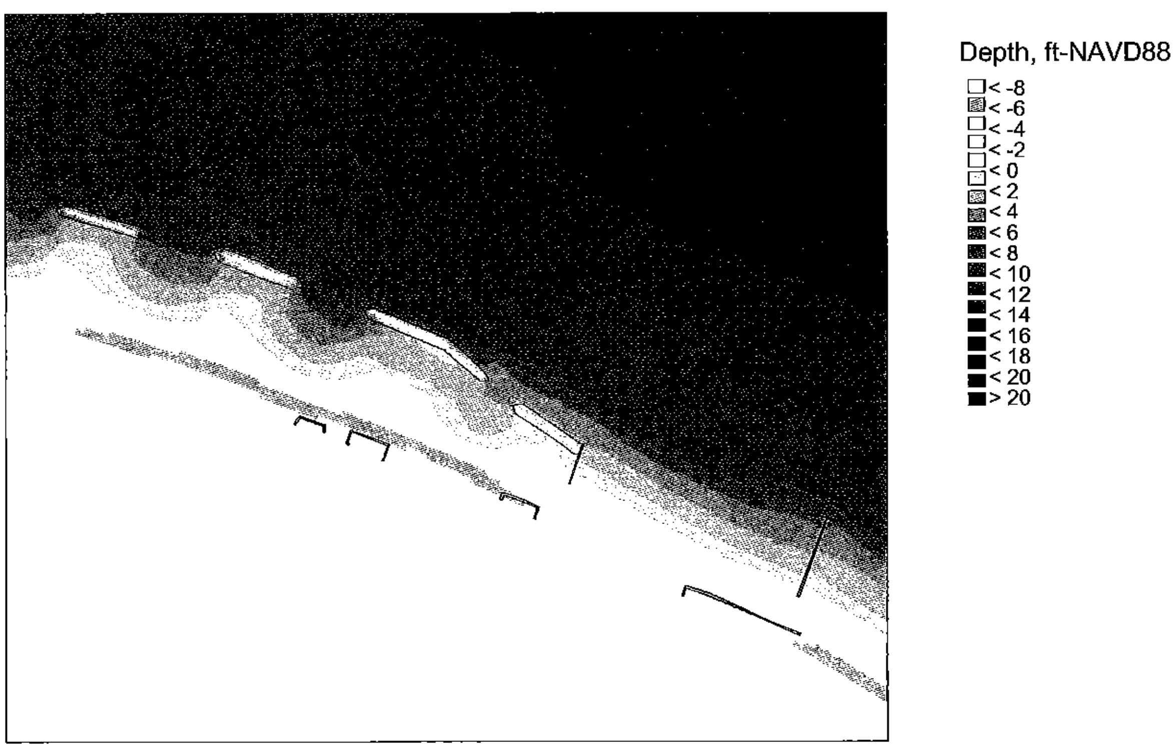


Figure V-12 Delft3D Initial and Final Bathymetries for Existing Conditions Scenario

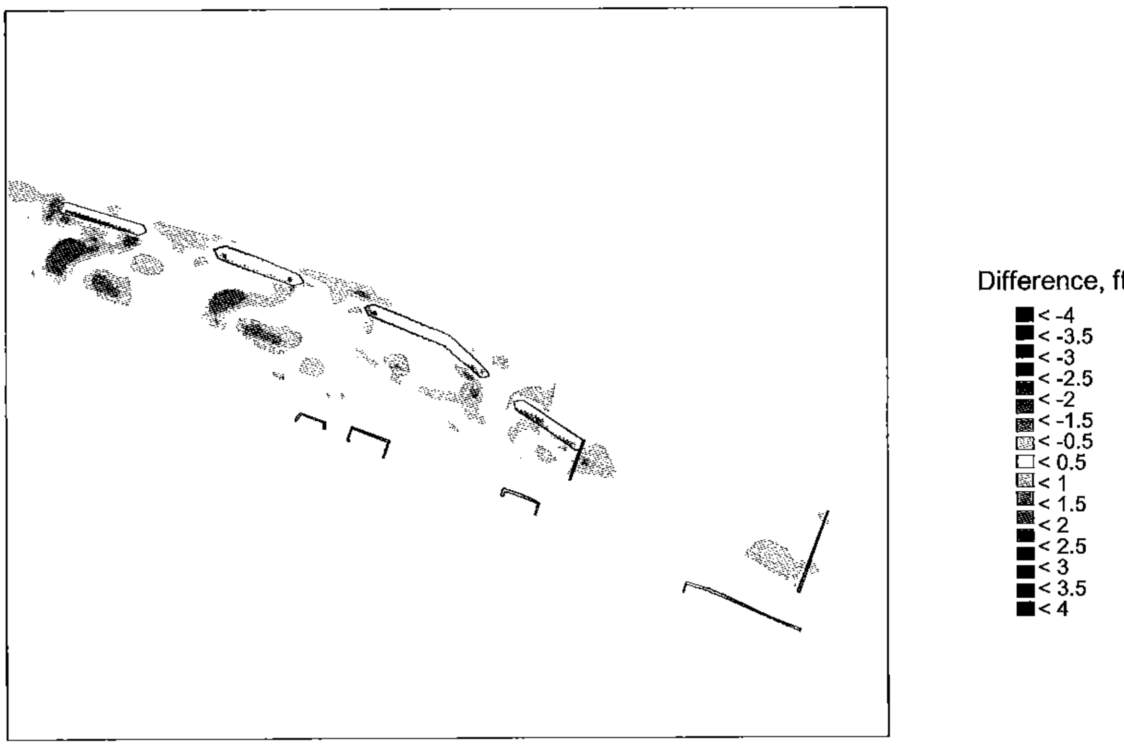


Figure V-13 Delft3D Accumulated Changes for Existing Conditions Scenario

H. MODELING OF PREFERRED ALTERNATIVES

Proposed alternative models were run in order to determine the impacts on the study area with the two selected erosion control alternatives in place. The modeled erosion control alternatives involved the removal and/or modification of existing structures and/or the addition of new erosion control structures. The models were also used to assess and compare the relative performance of these proposed alternatives under wave and hydrodynamic conditions roughly equivalent to a 5-year period. Option 1 involved the removal of the toe extension on breakwater 7 and Option 4a involved the removal of the toe extension on breakwater 7 and spur and the construction of a new breakwater offshore.

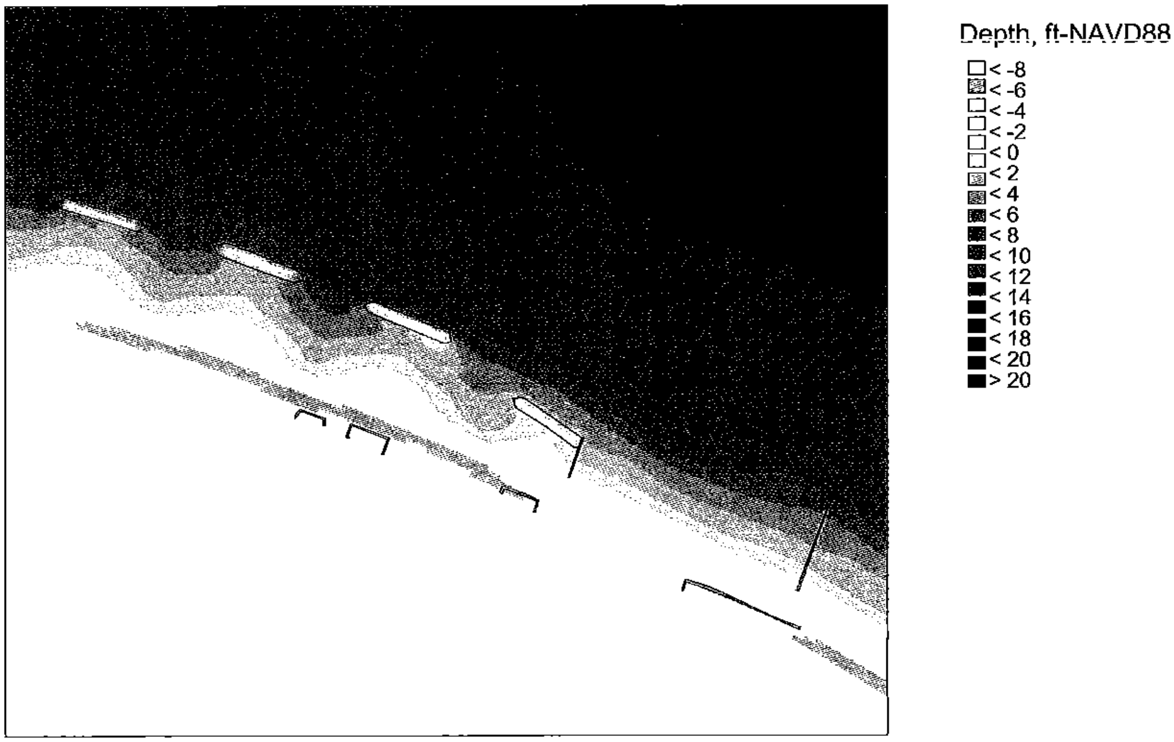
1. Option 1 Results

With the absence of the toe extension on breakwater 7, this option allows more sediment transport to pass through the local area of interest. **Figure V-14** shows the initial and final bathymetries for the Option 1 simulation. **Figure V-15** shows the accumulated changes for the Option 1 simulation. As shown in the bottom pane of **Figure V-14** and **Figure V-15**, there are increased accretion patterns landward of breakwater 7. These patterns may be attributed to the increased gap width between breakwater 7 and the existing spur, thus allowing more sediment transport to pass through the local area of interest when compared to the Existing Conditions run. However, the accelerated accretion behind breakwater 7 (in comparison to the other breakwaters) does raise a concern of tombolo formation and blocking of sediment transport from the east. This response is consistent with GENESIS simulation results.

2. Option 4a Results

Similar to Option 1, this option also allows more sediment transport to pass through the local area of interest. **Figure V-16** shows the initial and final bathymetries for the Option 4a simulation. **Figure V-17** shows the accumulated changes for the Option 4a simulation. It can be seen in the bottom pane of **Figure V-16** and **Figure V-17** that the accretion patterns landward of breakwater 7 are reduced when compared to Option 1 results. In addition, increased patterns of erosion and accretion are observed from the model results. These patterns may be attributed to the combined effects of the increased gap width between breakwater 7 and the new offshore breakwater as well as the gap width between groin 8 and the offshore breakwater. This option also allows for the development of erosional/depositional patterns behind breakwater 7 and the new breakwater, which are most similar to those patterns west of the immediate hotspot area. This observed shoreline response provides the smoothest transition across the area of interest without increasing the risk of blocking sediment transport from the east and recreating the problem. However, it is important to note that beach nourishment will still be required at the hotspot on occasion, but due to the improved transition, it is expected that the magnitude and frequency of nourishment will be significantly reduced from current levels. These results are in agreement with the GENESIS simulation results.

Initial Bathymetry



Final Bathymetry

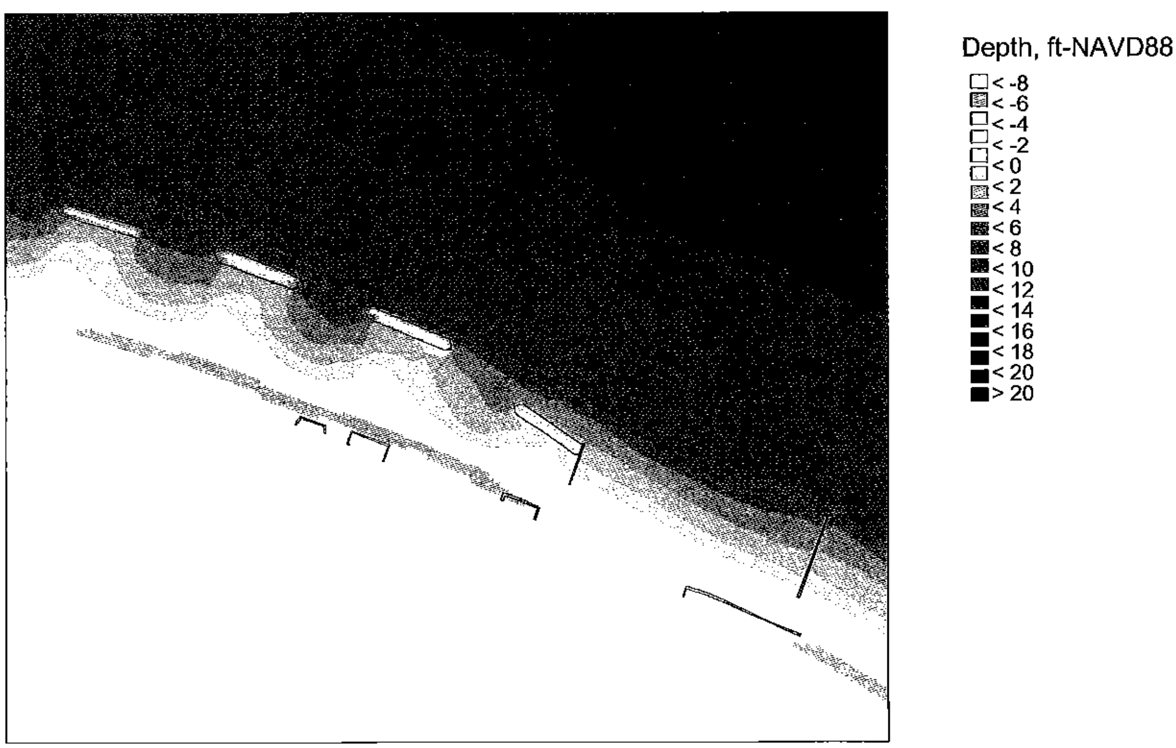


Figure V-14 Delft3D Initial and Final Bathymetries for Option 1

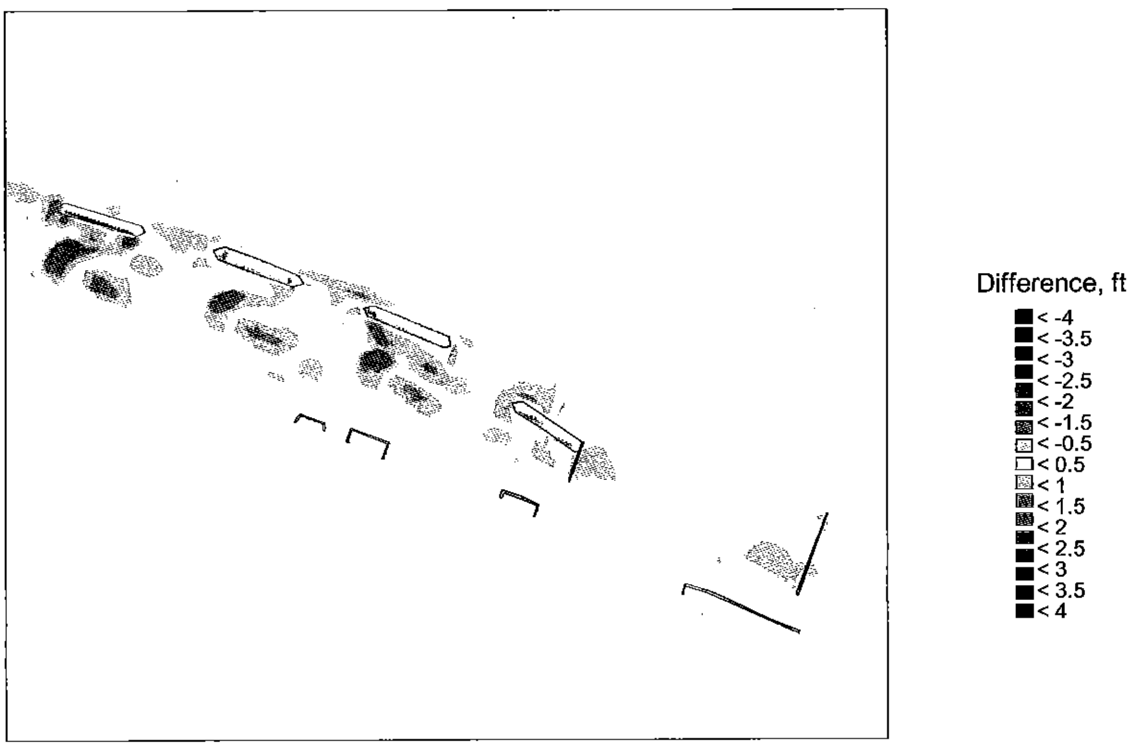
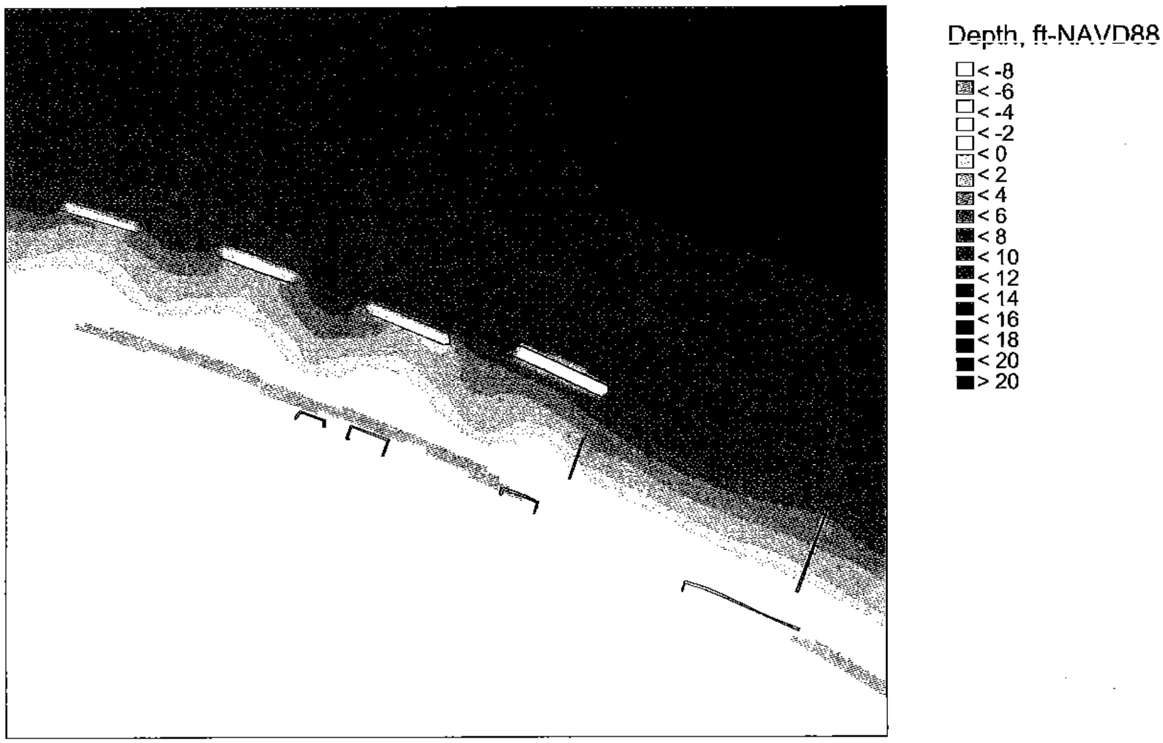


Figure V-15 Delft3D Accumulated Changes for Option 1

Initial Bathymetry



Final Bathymetry

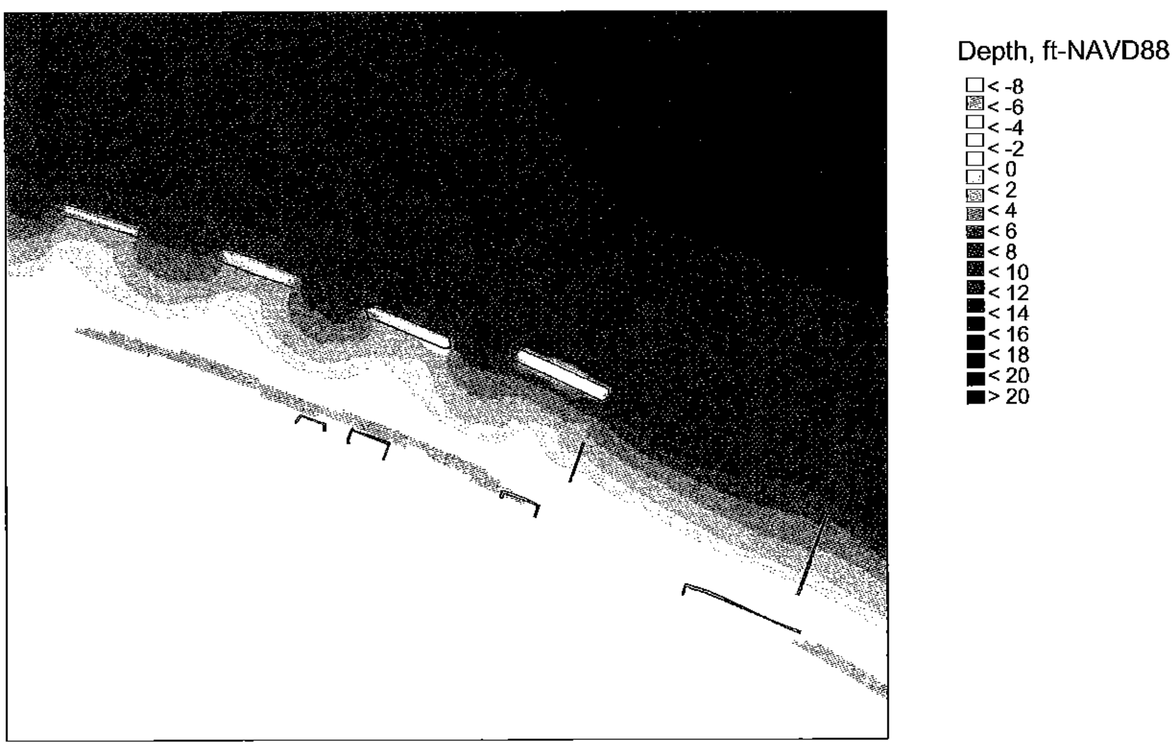


Figure V-16 Delft3D Initial and Final Bathymetries for Option 4a

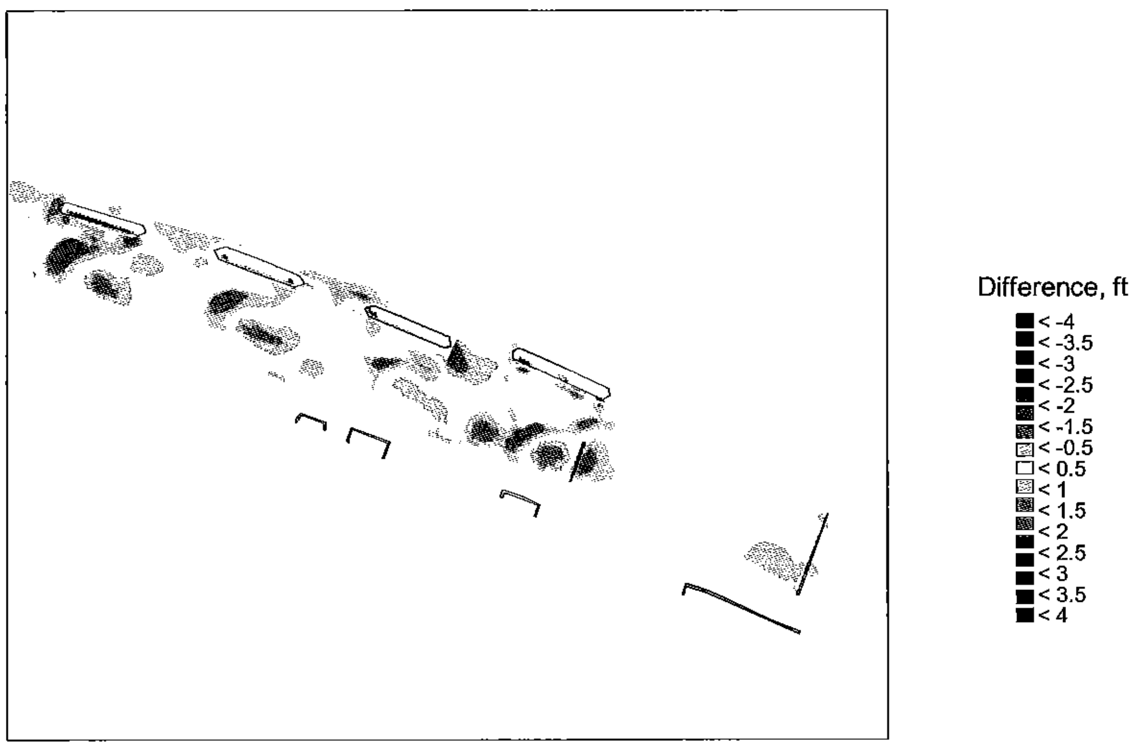


Figure V-17 Delft3D Accumulated Changes for Option 4a

VI. ANALYTICAL ANALYSIS

In addition to the numerical modeling completed for the existing study area, M&N also investigated analytical models to verify our understanding of the project area. Analytical models used included work completed by Suh and Dalrymple (for offshore breakwaters) and Sylvester and Hsu (artificial headlands) (Dean & Dalrymple, 2002). **Figure VI-1** illustrates the parameters used in determining the equilibrium planform shape by the Silverster and Hsu methodology. Both analytic models describe the maximum expected shoreline offset (shown as 'a' in **Figure VI-1**) as a factor of structure length, gap spacing between structures (shown as 'b' in **Figure VI-1**), depth of water at the structure, and incident angle of predominant wave direction.

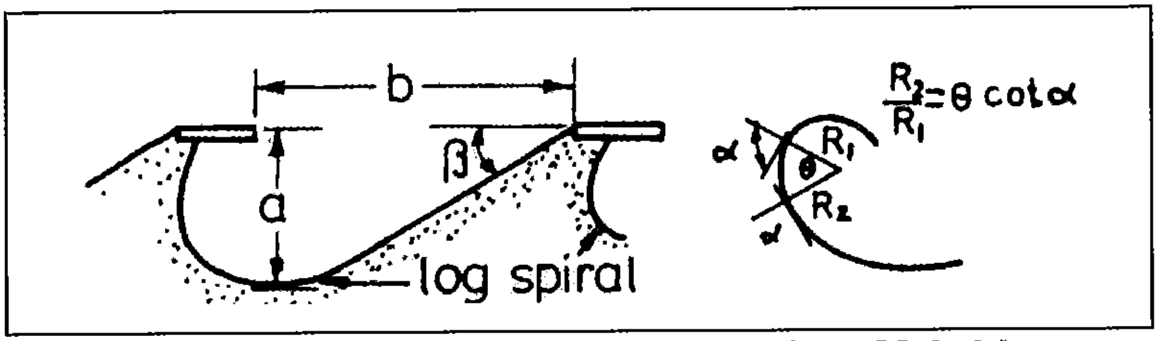


Figure VI-1 Illustration of Equilibrium Planform Shape Methodology (Silvester and Hsu, 1993)

These methodologies were first applied for three breakwaters within the field at the 800 Block area which have appeared to reach equilibrium conditions. The structure length and gap spacing, etc. were all measured for equilibrium conditions (Oct 1999 shoreline – before spur groin and toe extension were constructed) and recorded. These measured parameters are depicted in **Figure VI-2**. The design ratios were then calculated for equilibrium conditions at the project site, with the most important design ratio being a/b (shoreline offset/gap length) calculated to be 1.2 for the equilibrium conditions. This ratio is over 1.0, but this is not surprising given the permeability of the structures and the point of fixity being landward of the breakwater. The other design ratios were calculated for existing conditions and do fall within expected ranges for design conditions (i.e., so that tombolos are likely not to form, etc.).

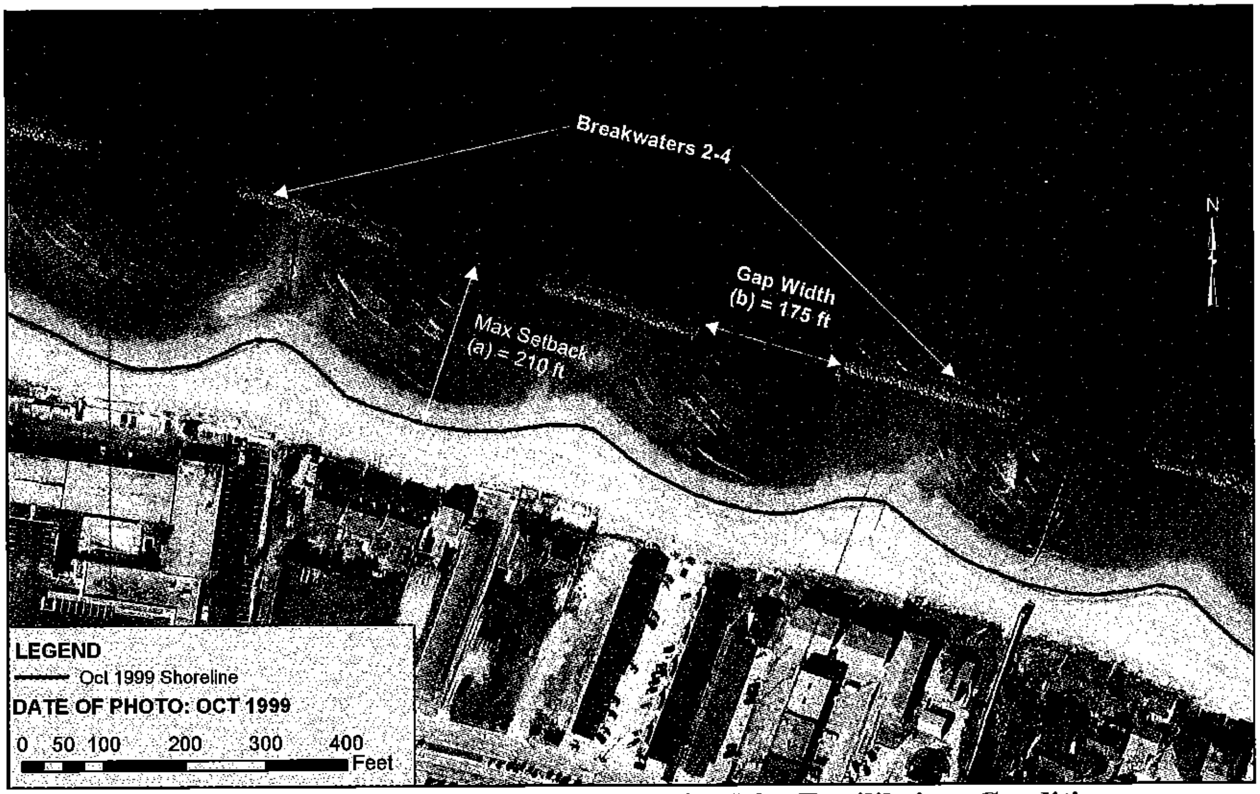


Figure VI-2 Measured Parameters Obtained for Equilibrium Conditions

Applying the analytic design ratios developed previously to the spur groin and toe extension after construction show why these structures have not been successful at mitigating the erosional issues at the hotspot. **Figure VI-3** presents the offset computed for the hotspot area following construction of the groin spur using the previous ratio of 1.2 which was computed from the equilibrium conditions. The spur groin was especially problematic given the wide gap distance that still remained. In fact, the measured shoreline position shows that the maximum offset had still not been reached. **Figure VI-4** shows the results for the same analysis applied following construction of the toe extension on breakwater 7. While the toe extension may have reduced the gap distance, the shoreline is now so locked in place that sediment transport from the east is blocked from reaching western portions of the study area.

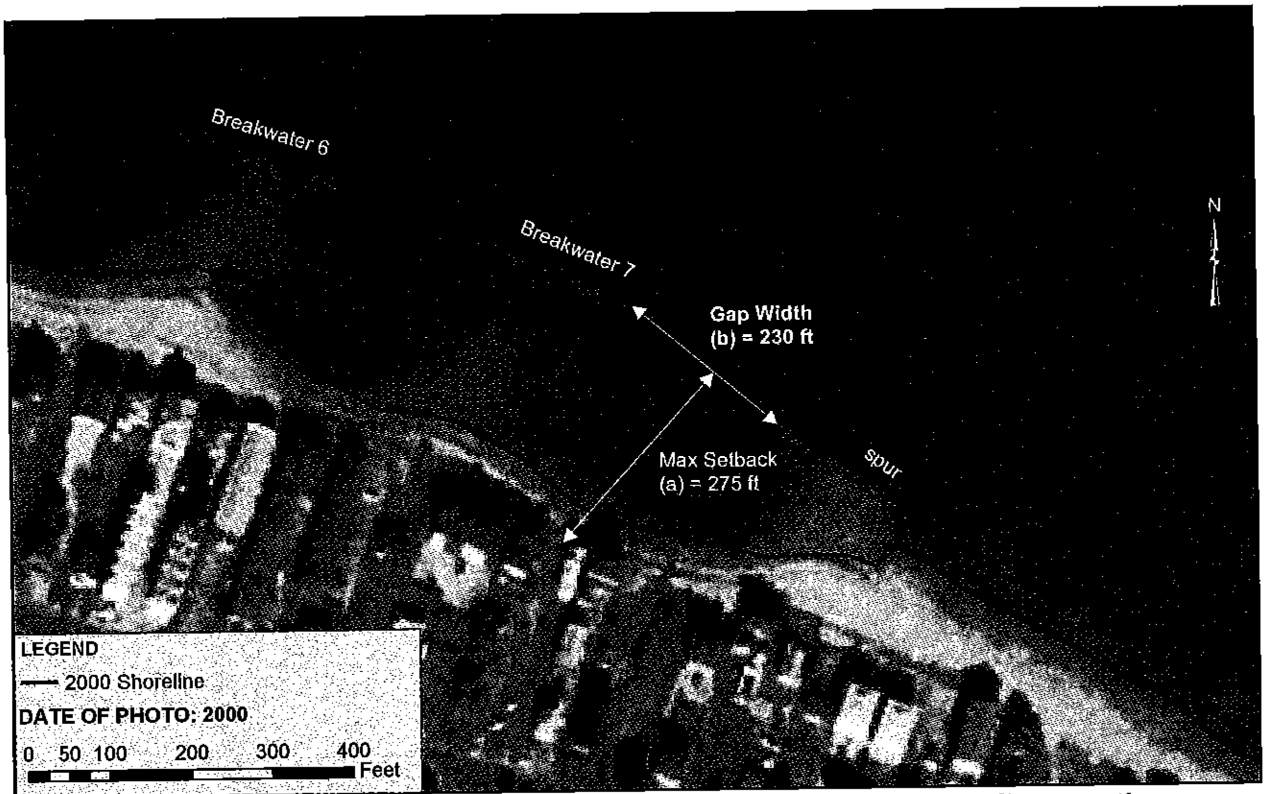


Figure VI-3 Results of Analytical Analysis following Spur Groin Construction

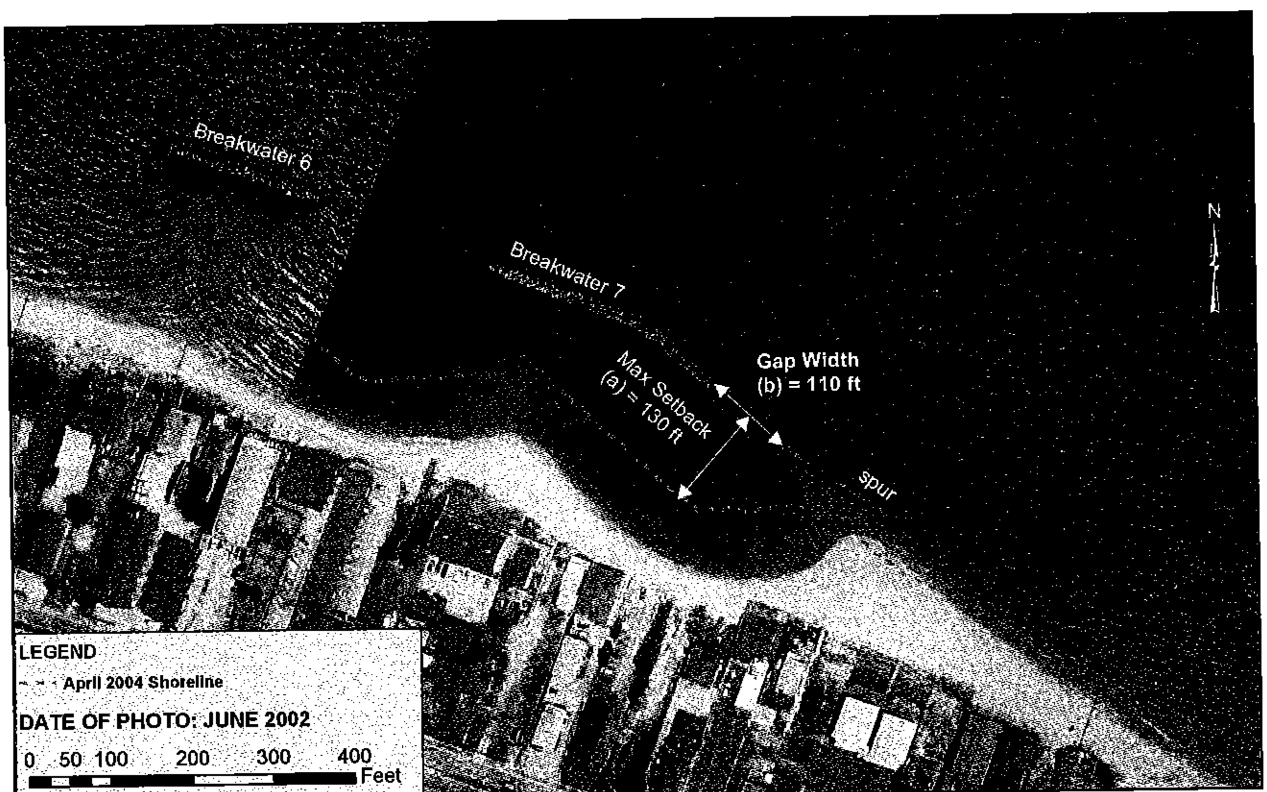


Figure VI-4 Results of Analytical Analysis following Toe Extension Construction

Applying the analytic design ratios developed previously to the structural configuration implemented in Option 4a shows that the maximum expected shoreline offset is approximately 210'. **Figure VI-5** shows the results for the analytical analysis when applied for Option 4a. Plotting this offset relative to the GENESIS model results shows relatively good agreement with the shoreline position after an 8-yr time period. This analysis gave M&N further verification that Option 4a would definitely be preferred to Option 1 which would likely cause a shoreline offset much more landward of Option 4a.

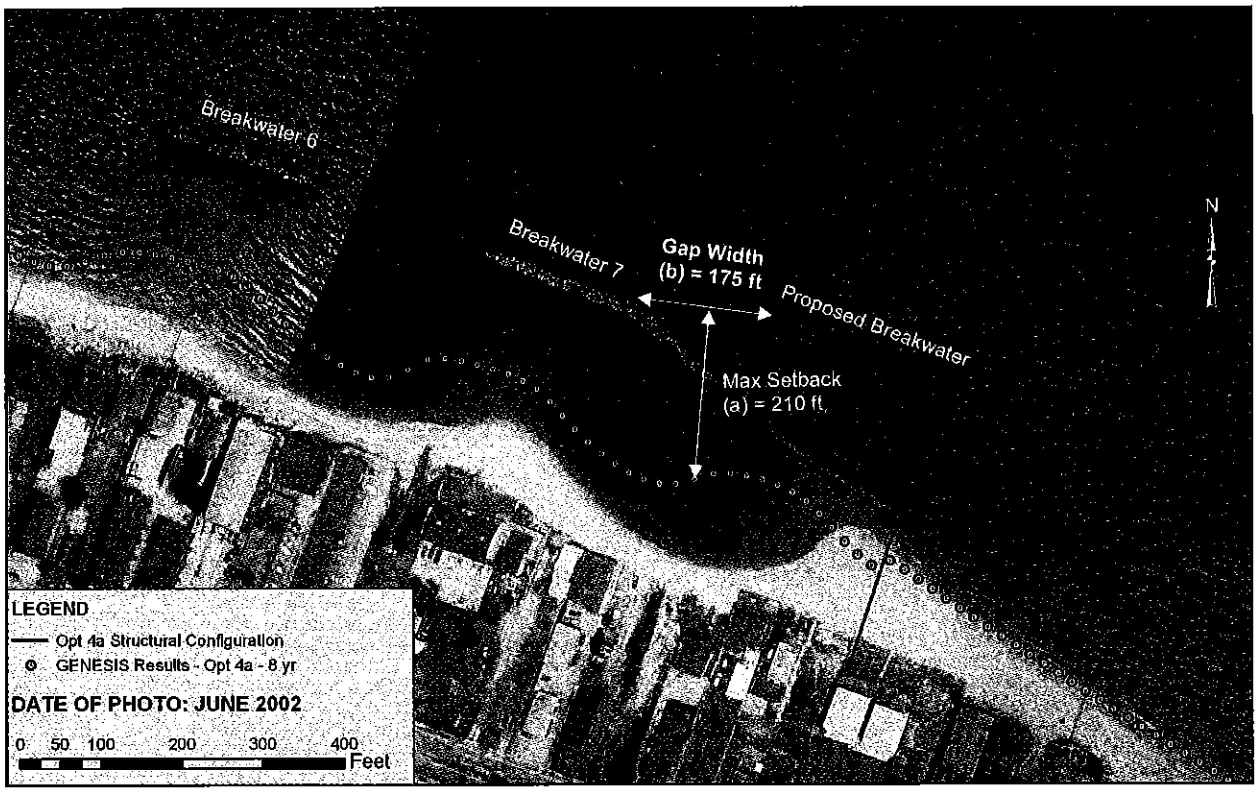


Figure VI-5 Results of Analytical Analysis for Option 4a

VII. STUDY FINDINGS & RECOMMENDATIONS

This study involved an extensive review of historical data and engineering activities at the 800 Block area followed by complex numerical and analytical modeling of the existing system, all of which aided in the determination of the probable cause of erosion at the study area. The GENESIS model was used to simulate the long-term shoreline change induced primarily by wave action with numerous erosion control alternatives in place. Based on the results of the GENESIS model, two alternatives, Option 1 and Option 4a, were selected for further modeling in Delft3D and by analytical procedures. The Delft3D model was used to assess and compare the relative performance of the preferred alternatives under representative wave/surge conditions.

The review and analysis of historical data at the 800 Block study area proved to be a crucial aspect of this study, establishing historical shoreline change trends and the relation of these trends to engineering interventions at the project site. In general, M&N concluded that the hotspot is located at a unique position along the major bend in the Ocean View shoreline where the site is subject to increased sediment losses due to relative shoreline position to predominant wave direction. With the numerous erosion control alternatives that have been implemented, the historical data reveals that longshore sediment transport may have been interrupted on an increasing basis with each structural modification.

Based on the GENESIS and Delft3D model results, Option 4a is the recommended alternative for erosion control at the 800 Block area. This option involves removal of the toe extension and groin spur and the addition of a new breakwater offshore. This alternative was selected over Option 1 because the GENESIS model results showed an improved transition of the shoreline across the entire hotspot without significant negative impacts on the updrift and downdrift shorelines.

The Delft3D model results further verify the erosion and accretion patterns that can be expected to occur if Option 4a were implemented. These patterns indicate that while erosion may occur within the embayments between structures, this erosion is less than observed for existing conditions and is more balanced across the entire hotspot with Option 4a implemented. The Delft3D model results for Option 1 indicate more significant accretion behind the existing breakwater 7, which could potentially lead to tombolo formation and further blocking of sediment transport to the west. The analytical analysis further supports the GENESIS and Delft3D model results. Therefore, Option 4a remains the recommended alternative for erosion control at the 800 Block area. The opinion of probable cost for Option 4a is $660,000.

Through this study of the 800 Block area, M&N has gained a full appreciation of the uniqueness of this study area and the special challenges that it has presented others in the past. The historical analyses and numerical modeling results show that the area will always be a hotspot due to the break in the natural shoreline alignment. Therefore, immediate and periodic beach nourishment will always be required here. Based on the numerical and analytical modeling of numerous alternatives, Option 4a will best improve the shoreline transition at this natural hotspot area and balance the sediment transport through this area. If shoreline behavior is still an issue after this project is completed (i.e., if the site wave conditions are different than those used in the study which were transformed from Duck, NC), logical additions to this project would include shortening of the groins and construction of additional breakwaters to the east. However, based on the analysis and modeling to date, these additional measures do not appear cost effective for potential benefits gained.

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APPENDIX A

Detailed Opinions of Probable Costs for Modeled Alternatives

OPINION OF PROBABLE COST		DATE PREPARED 01/18/05	SHEET 1 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #1 Remove and Dispose of Toe Extension	STATUS OF DESIGN Opinion of Probable Cost Alternative #1		JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY NUMBER	QUANTITY UNIT	MATERIAL COST UNIT COST	MATERIAL COST TOTAL	LABOR COST UNIT COST	LABOR COST TOTAL	ENGINEERING ESTIMATE UNIT COST	ENGINEERING ESTIMATE TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Immediately East of Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	0	EA	$30,000.00	$0.00	$20,000.00	$0.00	$50,000.00	$0.00
							SUBTOTAL	**$0.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	0	ton	$0.00	$0.00	$35.00	$0.00	$35.00	$0.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	1613	ton	$0.00	$0.00	$40.00	$64,520.00	$40.00	$64,520.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$170,975.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Additional Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone from Spur and Toe Ext.	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #2								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	0	EA	$30,000.00	$0.00	$20,000.00	$0.00	$50,000.00	$0.00
							SUBTOTAL	**$0.00**

OPINION OF PROBABLE COST		DATE PREPARED 01/18/05	SHEET 2 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #1 Remove and Dispose of Toe Extension	STATUS OF DESIGN Opinion of Probable Cost Alternative #1		JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				**$30,000.00**		**$140,975.00**		**$170,975.00**
Contingency	20%							$34,195.00
Design/P&S/Construction Admin	12%							$20,517.00
							GRAND TOTAL	**$225,687.00**
							SAY	**$230,000**

OPINION OF PROBABLE COST		DATE PREPARED 01/18/05	SHEET 1 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #2 Remove Toe Extension & 100' of Groin at Spur	STATUS OF DESIGN Opinion of Probable Cost Alternative #2		JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	100	FT	$50.00	$5,000.00	$250.00	$25,000.00	$300.00	$30,000.00
Groin Immediately East of Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$80,000.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	0	ton	$0.00	$0.00	$35.00	$0.00	$35.00	$0.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	1613	ton	$0.00	$0.00	$40.00	$64,520.00	$40.00	$64,520.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$170,975.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Additional Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone from Spur and Toe Ext.	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #2								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	0	EA	$30,000.00	$0.00	$20,000.00	$0.00	$50,000.00	$0.00
							SUBTOTAL	**$0.00**

OPINION OF PROBABLE COST

DATE PREPARED 01/18/05

SHEET 2 2

ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #2 Remove Toe Extension & 100' of Groin at Spur	STATUS OF DESIGN Opinion of Probable Cost Alternative #2	JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				**$65,000.00**		**$185,975.00**		**$250,975.00**
Contingency	20%							$50,195.00
Design/P&S/Construction Admin	12%							$30,117.00
							GRAND TOTAL	**$331,287.00**
							SAY	**$340,000**

OPINION OF PROBABLE COST

DATE PREPARED: 01/18/05	SHEET: 1 of 2	
ACTIVITY AND LOCATION: Ocean View, Norfolk, Virginia	CONSTRUCTION CONTRACT NO.:	IDENTIFICATION NUMBER:
PROJECT TITLE: 800 Block Study - Alternative #3, Remove and Dispose of Toe Extension & Spur	ESTIMATED BY: Moffatt & Nichol	CATEGORY CODE NUMBER:
	STATUS OF DESIGN: Opinion of Probable Cost Alternative #3	JOB ORDER NUMBER: 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Immediately East of Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	0	EA	$30,000.00	$0.00	$20,000.00	$0.00	$50,000.00	$0.00
							SUBTOTAL	**$0.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	1495	ton	$0.00	$0.00	$35.00	$52,325.00	$35.00	$52,325.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	3108	ton	$0.00	$0.00	$40.00	$124,320.00	$40.00	$124,320.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$283,100.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Additional Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone from Spur and Toe Ext.	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #2								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	0	EA	$30,000.00	$0.00	$20,000.00	$0.00	$50,000.00	$0.00
							SUBTOTAL	**$0.00**

OPINION OF PROBABLE COST

DATE PREPARED: 01/18/05	SHEET 2 of 2	
ACTIVITY AND LOCATION: Ocean View, Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
	ESTIMATED BY: Moffatt & Nichol	CATEGORY CODE NUMBER
PROJECT TITLE: 800 Block Study - Alternative #3, Remove and Dispose of Toe Extension & Spur	STATUS OF DESIGN: Opinion of Probable Cost Alternative #3	JOB ORDER NUMBER: 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				**$30,000.00**		**$253,100.00**		**$283,100.00**
Contingency	20%							$56,620.00
Design/P&S/Construction Admin	12%							$33,972.00
							GRAND TOTAL	**$373,692.00**
							SAY	**$380,000**

OPINION OF PROBABLE COST

DATE PREPARED: 01/18/05	SHEET 1 of 2	
ACTIVITY AND LOCATION: Ocean View, Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
	ESTIMATED BY: Moffatt & Nichol	CATEGORY CODE NUMBER
PROJECT TITLE: 800 Block Study - Alternative #4a, Use Toe Ext. & Spur to Form New Breakwater	STATUS OF DESIGN: Opinion of Probable Cost Alternative #4a	JOB ORDER NUMBER: 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Immediately East of Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	0	EA	$30,000.00	$0.00	$20,000.00	$0.00	$50,000.00	$0.00
							SUBTOTAL	**$0.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	1495	ton	$0.00	$0.00	$35.00	$52,325.00	$35.00	$52,325.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$158,780.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	2436	ton	$0.00	$0.00	$40.00	$97,440.00	$40.00	$97,440.00
Additional Armor Stone	2000	ton	$40.00	$80,000.00	$40.00	$80,000.00	$80.00	$160,000.00
Bedding Stone from Spur and Toe Ext.	670	ton	$0.00	$0.00	$40.00	$26,800.00	$40.00	$26,800.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #2								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$340,642.00**

OPINION OF PROBABLE COST						DATE PREPARED 01/18/05		SHEET 2	2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia			CONSTRUCTION CONTRACT NO.					IDENTIFICATION NUMBER	
PROJECT TITLE 800 Block Study - Alternative #4a Use Toe Ext. & Spur to Form New Breakwater			ESTIMATED BY Moffatt & Nichol					CATEGORY CODE NUMBER	
			STATUS OF DESIGN Opinion of Probable Cost Alternative #4a					JOB ORDER NUMBER 5197-08	
ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE		
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL	
PROJECT SUBTOTAL				**$144,268.00**		**$355,154.00**		**$499,422.00**	
Contingency	20%							$99,884.40	
Design/P&S/Construction Admin	12%							$59,930.64	
							GRAND TOTAL	**$659,237.04**	
							SAY	**$660,000**	

OPINION OF PROBABLE COST

DATE PREPARED	01/18/05	SHEET	1 - 2
ACTIVITY AND LOCATION: Ocean View, Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY: Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE: 800 Block Study - Alternative #4b, Use Toe Ext. & Spur to Form New Breakwater & Shorten S	STATUS OF DESIGN: Opinion of Probable Cost Alternative #4b		JOB ORDER NUMBER: 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	50	FT	$50.00	$2,500.00	$250.00	$12,500.00	$300.00	$15,000.00
Groin Immediately East of Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$65,000.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	1495	ton	$0.00	$0.00	$35.00	$52,325.00	$35.00	$52,325.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$158,780.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	2436	ton	$0.00	$0.00	$40.00	$97,440.00	$40.00	$97,440.00
Additional Armor Stone	2000	ton	$40.00	$80,000.00	$40.00	$80,000.00	$80.00	$160,000.00
Bedding Stone from Spur and Toe Ext.	670	ton	$0.00	$0.00	$40.00	$26,800.00	$40.00	$26,800.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #2								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$340,642.00**

OPINION OF PROBABLE COST

DATE PREPARED	01/18/05
SHEET	2 2
ACTIVITY AND LOCATION	Ocean View Norfolk, Virginia
CONSTRUCTION CONTRACT NO.	
IDENTIFICATION NUMBER	
ESTIMATED BY	Moffatt & Nichol
CATEGORY CODE NUMBER	
PROJECT TITLE	800 Block Study - Alternative #4b Use Toe Ext. & Spur to Form New Breakwater & Shorten S
STATUS OF DESIGN	Opinion of Probable Cost Alternative #4b
JOB ORDER NUMBER	5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				**$176,768.00**		**$387,654.00**		**$564,422.00**
Contingency	20%							$112,884.40
Design/P&S/Construction Admin	12%							$67,730.64
							GRAND TOTAL	**$745,037.04**
							SAY	**$750,000**

OPINION OF PROBABLE COST

		DATE PREPARED 01/18/05	SHEET 1 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #5 Use Toe Ext. & Spur to Form New Breakwater & Shorten E	STATUS OF DESIGN Opinion of Probable Cost Alternative #5		JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Immediately East of Spur	150	FT	$50.00	$7,500.00	$250.00	$37,500.00	$300.00	$45,000.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$95,000.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	1495	ton	$0.00	$0.00	$35.00	$52,325.00	$35.00	$52,325.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$158,780.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	2436	ton	$0.00	$0.00	$40.00	$97,440.00	$40.00	$97,440.00
Additional Armor Stone	2000	ton	$40.00	$80,000.00	$40.00	$80,000.00	$80.00	$160,000.00
Bedding Stone from Spur and Toe Ext.	670	ton	$0.00	$0.00	$40.00	$26,800.00	$40.00	$26,800.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #2								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$340,642.00**

OPINION OF PROBABLE COST

DATE PREPARED: 01/18/05	SHEET 2	2
ACTIVITY AND LOCATION: Ocean View, Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
	ESTIMATED BY: Moffatt & Nichol	CATEGORY CODE NUMBER
PROJECT TITLE: 800 Block Study - Alternative #5, Use Toe Ext. & Spur to Form New Breakwater & Shorten E	STATUS OF DESIGN: Opinion of Probable Cost Alternative #5	JOB ORDER NUMBER: 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				**$181,768.00**		**$412,654.00**		**$594,422.00**
Contingency	20%							$118,884.40
Design/P&S/Construction Admin	12%							$71,330.64
							GRAND TOTAL	**$784,637.04**
							SAY	**$790,000**

OPINION OF PROBABLE COST	DATE PREPARED 01/18/05	SHEET 1 OF 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #6 Use Toe Ext. & Spur for Breakwater,Shorten East Groin, Build E	STATUS OF DESIGN Opinion of Probable Cost Alternative #6	JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Immediately East of Spur	150	FT	$50.00	$7,500.00	$250.00	$37,500.00	$300.00	$45,000.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$95,000.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	1495	ton	$0.00	$0.00	$35.00	$52,325.00	$35.00	$52,325.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$158,780.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	2436	ton	$0.00	$0.00	$40.00	$97,440.00	$40.00	$97,440.00
Additional Armor Stone	2000	ton	$40.00	$80,000.00	$40.00	$80,000.00	$80.00	$160,000.00
Bedding Stone from Spur and Toe Ext.	670	ton	$0.00	$0.00	$40.00	$26,800.00	$40.00	$26,800.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #2								
Armor Stone	4328	ton	$40.00	$173,120.00	$40.00	$173,120.00	$80.00	$346,240.00
Bedding Stone	670	ton	$30.00	$20,100.00	$40.00	$26,800.00	$70.00	$46,900.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #3								
Armor Stone	0	ton	$40.00	$0.00	$40.00	$0.00	$80.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$740,184.00**

OPINION OF PROBABLE COST		DATE PREPARED 01/18/05	SHEET 2 OF 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #6 Use Toe Ext. & Spur for Breakwater,Shorten East Groin, Build B	STATUS OF DESIGN Opinion of Probable Cost Alternative #6		JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				**$379,256.00**		**$614,708.00**		**$993,964.00**
Contingency	20%							$198,792.80
Design/P&S/Construction Admin	12%							$119,275.68
							GRAND TOTAL	**$1,312,032.48**
							SAY	**$1,320,000**

OPINION OF PROBABLE COST	DATE PREPARED 01/18/05	SHEET 1 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #7 Use Toe Ext. & Spur for Breakwater,Shorten East Groin, Bu	STATUS OF DESIGN Opinion of Probable Cost Alternative #7	JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Immediately East of Spur	150	FT	$50.00	$7,500.00	$250.00	$37,500.00	$300.00	$45,000.00
Groin Construction								
Groin Immediately West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Second Groin West of Spur	0	FT	$750.00	$0.00	$750.00	$0.00	$1,500.00	$0.00
Mob/Demob for Groin Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$95,000.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	1495	ton	$0.00	$0.00	$35.00	$52,325.00	$35.00	$52,325.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$158,780.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	2436	ton	$0.00	$0.00	$40.00	$97,440.00	$40.00	$97,440.00
Additional Armor Stone	2000	ton	$40.00	$80,000.00	$40.00	$80,000.00	$80.00	$160,000.00
Bedding Stone from Spur and Toe Ext.	670	ton	$0.00	$0.00	$40.00	$26,800.00	$40.00	$26,800.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #2								
Armor Stone	4328	ton	$40.00	$173,120.00	$40.00	$173,120.00	$80.00	$346,240.00
Bedding Stone	670	ton	$30.00	$20,100.00	$40.00	$26,800.00	$70.00	$46,900.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #3								
Armor Stone	4328	ton	$40.00	$173,120.00	$40.00	$173,120.00	$80.00	$346,240.00
Bedding Stone	670	ton	$30.00	$20,100.00	$40.00	$26,800.00	$70.00	$46,900.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$1,139,726.00**

OPINION OF PROBABLE COST		DATE PREPARED 01/18/05	SHEET 2 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #7 Use Toe Ext. & Spur for Breakwater,Shorten East Groin, Bu	STATUS OF DESIGN Opinion of Probable Cost Alternative #7		JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				$576,744.00		$816,762.00		$1,393,506.00
Contingency	20%							$278,701.20
Design/P&S/Construction Admin	12%							$167,220.72
							GRAND TOTAL	$1,839,427.92
							SAY	$1,840,000

OPINION OF PROBABLE COST		DATE PREPARED 01/18/05	SHEET 1 2
ACTIVITY AND LOCATION Ocean View Norfolk, Virginia	CONSTRUCTION CONTRACT NO.		IDENTIFICATION NUMBER
	ESTIMATED BY Moffatt & Nichol		CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #8 Use Toe Ext. & Spur for Breakwater, Build 2 Groins at Ho	STATUS OF DESIGN Opinion of Probable Cost Alternative #8		JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
GROIN WORK								
Groin Removal/Shortening								
Groin at Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Immediately East of Spur	0	FT	$50.00	$0.00	$250.00	$0.00	$300.00	$0.00
Groin Construction								
Groin Immediately West of Spur	150	FT	$750.00	$112,500.00	$750.00	$112,500.00	$1,500.00	$225,000.00
Second Groin West of Spur	150	FT	$750.00	$112,500.00	$750.00	$112,500.00	$1,500.00	$225,000.00
Mob/Demob for Groin Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$500,000.00**
SPUR/TOE EXTENSION WORK								
Spur Work								
Remove Spur	1495	ton	$0.00	$0.00	$35.00	$52,325.00	$35.00	$52,325.00
Toe Extension Work								
Remove Toe Extension	1613	ton	$0.00	$0.00	$35.00	$56,455.00	$35.00	$56,455.00
Dispose of Spur/Toe Extension Rock	0	ton	$0.00	$0.00	$40.00	$0.00	$40.00	$0.00
Mob/Demob for Spur/Toe Ext. Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$158,780.00**
BREAKWATER WORK @ EL -8.5 FT								
Breakwater #1								
Armor Stone from Spur and Toe Ext.	2436	ton	$0.00	$0.00	$40.00	$97,440.00	$40.00	$97,440.00
Additional Armor Stone	2000	ton	$40.00	$80,000.00	$40.00	$80,000.00	$80.00	$160,000.00
Bedding Stone from Spur and Toe Ext.	670	ton	$0.00	$0.00	$40.00	$26,800.00	$40.00	$26,800.00
Filter Fabric	1067	SY	$4.00	$4,268.00	$2.00	$2,134.00	$6.00	$6,402.00
Breakwater #2								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Breakwater #3								
Armor Stone	0	ton	$35.00	$0.00	$40.00	$0.00	$75.00	$0.00
Bedding Stone	0	ton	$30.00	$0.00	$40.00	$0.00	$70.00	$0.00
Filter Fabric	0	SY	$4.00	$0.00	$2.00	$0.00	$6.00	$0.00
Mob/Demob for Breakwater Work	1	EA	$30,000.00	$30,000.00	$20,000.00	$20,000.00	$50,000.00	$50,000.00
							SUBTOTAL	**$340,642.00**

OPINION OF PROBABLE COST

DATE PREPARED 01/18/05 | SHEET 2 of 2

ACTIVITY AND LOCATION	CONSTRUCTION CONTRACT NO.	IDENTIFICATION NUMBER
Ocean View Norfolk, Virginia	ESTIMATED BY Moffatt & Nichol	CATEGORY CODE NUMBER
PROJECT TITLE 800 Block Study - Alternative #8 Use Toe Ext. & Spur for Breakwater, Build 2 Groins at Ho	STATUS OF DESIGN Opinion of Probable Cost Alternative #8	JOB ORDER NUMBER 5197-08

ITEM DESCRIPTION	QUANTITY		MATERIAL COST		LABOR COST		ENGINEERING ESTIMATE	
	NUMBER	UNIT	UNIT COST	TOTAL	UNIT COST	TOTAL	UNIT COST	TOTAL
PROJECT SUBTOTAL				**$399,268.00**		**$600,154.00**		**$999,422.00**
Contingency	20%							$199,884.40
Design/P&S/Construction Admin	12%							$119,930.64
							GRAND TOTAL	**$1,319,237.04**
							SAY	**$1,320,000**